Extent and quality of habitat for the endangered forty-spotted pardalote (*Pardalotus quadragintus*) at Howden, Tasmania

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Forty-spotted pardalote (*Pardalotus quadragintus*)   Photo by Graeme Chapman

Thesis submitted in partial fulfilment of the requirements for the degree of
Master of Applied Science
School of Geography and Environmental Studies
University of Tasmania, Hobart
October 2010

Statement of originality

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person expect where due acknowledgement is made in the text.

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Date 15 / 10 / 2010

Abstract

In 2009-2010 a survey of *Pardalotus quadragintus* (forty-spotted pardalote) found that there had been a 60 % decline in the species population size over the last 25 years. In some bird colonies, *Eucalyptus viminalis* (white gum) decline and dieback was considered to be the primary cause of this population decline. In contrast, one of the smallest *P. quadragintus* colonies, located at Howden (approximately 3 km south of the town of Kingston in Tasmania) declined from 20 to 10 birds over the last 10 years, despite *E. viminalis* in the area appearing to maintain sufficient quality to support the previous population size. The Howden habitat is located in a sub-urban landscape, in which the surrounding area has been extensively cleared over the last 10 years. Therefore, human related disturbances might be a causal factor for this declining bird population. However, a comprehensive habitat survey has not been undertaken to test this possibility. This study attempts to identify the potential causes of the decline in the Howden population and determine the key habitat characteristics that influence the habitat preferences of this species. Recommendations for implementation of specific conservation actions are provided based upon the results of this study.

A survey of habitat quality and occurrence of *P. quadragintus* was conducted between March and September 2010 in the Peter Murrell Reserve and Conservation Area (the Reserve) and adjacent land. The survey identified 32 forest patches containing *E. viminalis*, which were separated into three groups based upon geographical position – Coffee Creek (29 ha), Mid-eastern (4.3 ha) and Channel Highway (6.5 ha). All of eight patches in the Mid-eastern and the Channel Highway groups were newly identified as potential habitat for *P. quadragintus*. Habitat attribute variables were surveyed at both patch and group levels. One result of this study was to increase the total estimated habitat size of *P. quadragintus* from 12 ha to 40 ha. Identification of this additional habitat potentially increases the local estimated population size of this species (previous estimations based on a habitat of 12 ha suggested that 10 birds occupy the area). However, the extremely small number of birds detected during the study period suggests that the estimated population size of 10 birds is likely to be correct.

The tree health of *E. viminalis* in the Coffee Creek habitat was examined by comparing the tree crown condition with that of trees from the 'Township' habitat on nearby Bruny Island. The result identified that the Coffee Creek habitat provided better habitat quality (e.g. crown condition, abundance of large *E. viminalis* trees and canopy coverage of *E. viminalis*) than that provided by the 'Township' habitat. Different environmental and land management factors (e.g. soil/rock types, topography and grazing history) between these two habitats were considered to differentially affect water holding capacity, altering the availability of water to plant species. Better tree health and habitat quality in Howden are consistent with a previous study and suggest that the decline of the *P. quadragintus* population at Howden may not be linked with habitat quality, rather human disturbances may be important.

The *P. quadragintus* detection rate did not show any strong association with the measured habitat characteristics believed to be favourable for *P. quadragintus*. This result suggests that the birds are not able to establish their natural ecological behaviour due to pressures from human related disturbances, rather they are forced to use lower quality habitat. A 50 % increase in the number of buildings adjacent to the Reserve between 1990 and 2005 was confirmed, and has likely brought more visitors to the Reserve and increased interspecific competition and predation of nestlings as a result of elevated edge effects. Increased levels of habitat isolation may also be partially attributable to the negative effects of human disturbance.

The central finding of this study is that even in situations where stands of *E. viminalis* forest have been reserved and sufficient habitat quality has been maintained, *P. quadragintus* may well not be saved from extinction if significant levels of human related disturbance occur in and around these habitats. Hence, it is essential that land managers consider both the immediate habitat of *P. quadragintus* and the surrounding landscape in order to protect the population in the Howden area. Monitoring of the population also needs to be undertaken to evaluate the impacts of any actions adopted and to increase our understanding of *P. quadragintus* ecology.

Acknowledgements

Many people kindly helped throughout this project. I would like to sincerely thank my supervisor Dr. Peter McQuillan for providing many hours of help throughout the entire project, and for his kindness and patience in guiding me through the process. I would also like to thank Dr. Sally Bryant from Tasmanian Land Conservancy for giving me this wonderful opportunity to study and involve conservation of *P. quadragintus* and providing invaluable advice and support throughout the entire project.

I would also like to sincerely thank the following people:

Andrew Harwood, for proofreading my report, and for his great patience and suggestions for effective academic writing and critical thinking and for giving encouragement.

Dr. Jon Marsden-Smedley, for producing a wonderful *E. viminalis* map and providing technical advice for using GPS and vegetation mapping.

Dr. Neil Davidson, for invaluable information of *E. viminalis* and eucalypt dieback and advice for eucalypt tree condition assessment technique.

Sib and Keith Corbett, for advice about vegetation mapping and providing an idea for *E. viminalis* survey technique.

Denis Abbott, for valuable information regarding *P. quadragintus* and visitors at the Peter Murrell Reserve from his long time experience and for helping conduct the *P. quadragintus* survey.

Landowners, Phil Cullen, Donald Hazell, and Northwestbay Golf Club for permission to survey on their land.

Dr. Eric Woehler, and Dr. Tonia Cochran for advice and ideas when selecting the project topic.

and, finally my partner Bruce Morley who helped me with field survey and report writing and gave me encouragement and mental support throughout this project. Without his support I would hardly have completed the entire Masters course.

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Chapter 1: General Introduction

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1.1 Habitat quality for birds

Recent ecological studies (Burbidge & McKenzie, 1989; Short & Smith, 1994) have detailed that numerous native species in Australia have seriously declined in range and abundance since European settlement due to dramatic environmental changes. These environmental changes include the diversion of scarce environmental resources to humans and introduced species, reduction in vegetation cover by introduced herbivores, changed fire regimes and increase direct predation by introduced species (Burbidge & McKenzie, 1989). The fragmentation of habitat is also a key causal factor by reducing the population size of species and making them more prone to extinction through chance fluctuations and genetic deterioration (Ford, 1989). A list of threatened fauna species classified by the *Environment Protection and Biodiversity Conservation Act 1999* notes that the number of fauna assessed as extinct, endangered or vulnerable rose by 35% in the last decade (Australian Bureau of Statistics, 2010). Understanding the factors that determine species distribution and the key elements of habitat quality is critical for the development of management actions to secure viable threatened species populations (Cameron & Cunningham, 2006). This study examines the key habitat elements that influence the habitat quality of the endangered Forty-spotted pardaloate (*Pardalotus quadragintus*) in southern Tasmania.

Distributions of animals are limited by a number of factors, such as barriers that prevent dispersal, a lack of suitable habitat including the absence of critical resources, interactions with other species, and physical and chemical factors (Krebs, 1994). While most bird species are highly mobile, these environmental factors can restrict their range of distribution. In other word, the patterns of distributions are the consequence of decisions made by individual birds in selecting their habitats (Wiens, 1989). Hall *et al.* (1997) defined "habitat" as the resources and conditions present in an area that is occupied by a species. Habitat selection in birds is influenced by a number of habitat quality characteristics, which are varied between species because the species have different combinations of attributes, such as food types, preferred nesting sites, and degree of susceptibility to competitors and human disturbance (Mörtberg, 2001; Kark *et al.*, 2007). "Habitat quality" is defined as the ability of the environment to provide conditions appropriate for sustaining individual and population of the species (Hall *et al.*, 1997). Few studies have examined the habitat quality for one particular bird species. This is probably because most birds are generalists rather than specialists, and the exact requirements of their habitat are difficult to clarify (Ford, 1989). Although there are a number of characteristics to evaluate the quality of habitat for forest birds, such as size of trees, vegetation coverage, interspecific composition, and soil types, abundance of food and nesting site are often considered as key characteristics of habitat quality to limit bird populations (Strong & Sherry, 2000; Johnson & Sherry, 2001; Parra & Telleria, 2004). This is because the abundance of food and nesting sites directly affects the reproductive success of bird species (Rodenhouse & Holmes, 1992).

Small woodland birds, especially habitat specialists with low mobility and sedentary attributes, are likely to be more vulnerable to landscape changes (Mörtberg, 2001). Habitat fragmentation degrades habitat quality for these birds by decreasing remnant size and by increasing edge effects resulting in an increase in the number of aggressive birds, interspecific competition, and predation. Hence, remnant area size can be one of the key habitat quality characteristics in the urban/sub-urban landscape (Lloyd, 2008). Some bird species that have large spatial requirements can not survive in remnant habitats that fall below a certain size. For other species with low mobility a small habitat can be a low quality habitat, because a small colony with no recruitment from other colonies is prone to extinction through chance fluctuations and genetic deterioration (Ford, 1989).

In order to develop appropriate habitat management strategies for threatened bird species, it is critical to determine which habitat quality characteristics of remnant forest patches are central to sustaining species populations. This information can help managers estimate suitable habitat size, which will make the estimation of abundance and dynamics of populations of bird species more accurate. This information is especially crucial for bird species – such as *Pardalotus quadragintus* – that clearly use certain plant species preferentially for foraging (Ford, 1989; Mörtberg, 2001; Cameron & Cunningham, 2006).

1.2 Summary of *Pardalotus quadragintus*

Pardalotus quadragintus is one of the smallest bird species in Australia, measuring around 9 to 10 cm in length and 9 to 13 g in weight. The species breeds from August to December with potentially two clutches of four or five eggs laid per season. The incubation period is between 16 to 20 days, with chicks fledging approximately 25 days later (Higgins & Peters, 2002). *P. quadragintus* is endemic to Tasmania, and has a small population size. The species is listed as endangered on the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and under Schedule 3.2 of the Tasmanian *Threatened Species Protection Act 1995* (Threatened Species Section, 2006). Brown (1986) reported that *P. quadragintus* has never been particularly common since it was first described by John Gould in 1838. While the bird was thought to have been rare, and their distribution restricted even prior to European settlement, the extent of their habitat and population is now even smaller than it was known to be earlier this century and last century (Bulman *et al.*, 1986). In 1997 the estimated population size was between 3,072 and 4,608 breeding birds, which was thought to have remained reasonably stable since 1986 (Threatened Species Section, 2006). However, the estimated population size has critically declined from 3,840 birds between 1994 and 1997 (Bryant, 1997) to 1,500 birds between 2009 and 2010 (Bryant, 2010; Bryant, unpublished). The distribution of *P. quadragintus* is now restricted to four main populations: Tinderbox Peninsula; Maria Island; Bruny Island; and Flinders Island, with some smaller populations found at Howden, Coningham and Mt Nelson.

There are a number of reasons proposed for the historical decline in the population of *P. quadragintus*, such as habitat loss, fragmentation and change in habitat structure followed by an increase in interspecific competition (Bryant, 1992). The most significant factor is loss of *Eucalyptus viminalis* (white gum) habitat through land clearing for grazing, agriculture and other developments (Bryant, 1992). In fact, grassy *E. viminalis* forest in south-east Tasmania has been reduced by greater than 50 % since European settlement (Threatened Species Section, 2006). *P. quadragintus* is almost entirely restricted to forest/woodland with *E. viminalis* as this tree it provides an abundance of food for the bird in the form of manna, lerps and leaf dwelling invertebrates. Manna is a sugary secretion produced from the leaves and twigs in response to insect attack, and lerps are the sugary exudates of some psyllids (Woinarski & Bulman, 1985; Bulman *et al.*, 1986; Dorr, 1999). *P. quadraginus* co-occurs with the two other pardalote species, *P. striatus* (striated pardalote) and *P. punctatus* (spotted pardalote). All three pardalote species are similar in size and occur in forests where *E. viminalis* is a dominant species (Woinarski & Rounsevell, 1983). *P. striatus* migrates to overwinter on the Australian mainland and *P. punctatus* may also disperse over long distances during the cold winter period which is also a time of lower insect numbers resulting in less manna and lerps. However, *P. quadragintus* is more sedentary and has limited dispersal ability (Woinarski & Rounsevell, 1983; Woinarski & Bulman, 1985). Dorr (1999) suggested the foliage size of *E. viminalis* is more suitable for foraging for *P. quadragintus* than other eucalyptus species, such as *E. obliqua* and *E. globulus*. Hence the distribution of *P. quadragintus* is dependant upon the distribution of *E. viminalis* and, therefore, loss of *E. viminalis* habitat directly affects the population of *P. quadragintus*. Woinarski and Rounsevell (1983) reported that *P. quadragintus* employs a strategy to maintain its population size by concentrating in a number of 'safe' large colonies which periodically recruits birds to small outlying colony which experience relatively frequent extinctions. However, since European settlement most of the large secure colonies have now critically declined resulting in the extinction of small local populations as well. Declining emigration of *P. quadragintus* from large colonies to small colonies also occurs as a result of habitat isolation promoted by habitat fragmentation. Because *P. quadragintus* has limited dispersal ability, habitat isolation can prevent the development of small subsidiary colonies.

Changes in habitat structure due to disturbances within the habitat and adjacent areas have also contributed to a decline in the population. Disturbances can be on a large scale, such as land clearing, housing and road development, as well as a small scale, such as creating a small picnic area and walking and cycling tracks. The creation of open spaces induces edge effects resulting in increased competition with other bird species which better tolerate edges, such as *Manorina melanocephala* (noisy minor) and *Pardalotus striatus* (striated pardalote) (Bryant, 1992). Increased predation opportunity is also a possible consequence of the edge effects. Woinarski and Bulman (1985) suggested that *P. quadragintus* with high territoriality and limited dispersal ability in a competitive environment makes it difficult for them to maintain their population. Through interspecific competition *P. quadragintus* can lose available nesting sites and food resources as well as experiencing a reduction in their energy levels caused by chasing other birds and less time for foraging. In addition, human activities may disturb them away from their preferred nesting and foraging habitats.

1.3 Aims of the study

A small population of *P. quadragintus* along Coffee Creek, located on the western edge of the Peter Murrell Reserve in Howden, was discovered in 1994 (Bryant, 1997). While the estimated population of the species in this reserve was approximately 20 birds in 1994 (Threatened Species Unit 1998), a recent study revealed the population has declined to 10 birds in 12 ha of suitable habitat (Bryant, 2010). Ecological studies of the relationships between bird species and their habitats have been central to improving bird habitat quality (Shabani *et al.*, 2009). Ford (1989) suggested that populations at risk of extinction need to be monitored and their habitat preferences accurately measured. Previous studies have identified the habitat preferences of *P. quadragintus* for *E. viminalis* and that a suitable habitat needs to include *E. viminalis* canopy cover of 10 % or more (Woinarski & Bulman, 1985; Brereton *et al.*, 1997; Dorr, 1999). The condition of *E. viminalis* in some of the *P. quadragintus* habitats has deteriorated over the past decade due to drought (Bryant, 2010), and this has contributed to a critical decline in the *P. quadragintus* population over the last 10 years. This decline may affect the survival of *P. quadragintus* into the future. In contrast, the Coffee Creek forest habitat appears to have retained sufficient mature *E. viminalis* in good condition to support the previously estimated *P. quadragintus* population (Bryant, 2010). If this is the case, the observed population decline at Howden may well be affected by other factors. However, a comprehensive tree condition survey in association with the *P. quadragintus* population has not been undertaken previously, and the reason for the declining bird population has not been examined in detail.

This study aims to provide management agencies with a guide to habitat requirements for *P. quadragintus*. A better understanding of the habitat quality for *P. quadragintus* may assist in the development of effective management strategies to minimise the risk of extinction to the Howden population. Four main objectives have been designed to achieve these aims, and these objectives are examined in a corresponding chapter of this report.

Objective 1: Identify all the locations of *E. viminalis* stands at Howden (Chapter 2)
Although a suitable habitat size of 12 ha for the Howden colony has been estimated in a previous report (Bryant, 2010), no comprehensive survey of *E. viminalis* has been undertaken. This study aimed to identify all the locations of *E. viminalis* stands in and around the Peter Murrell Reserve to increase the accuracy of the estimated suitable habitat size and *P. quadragintus* population size.

Objective 2: Correlate the *E. viminalis* habitat condition to the decline of the *P. quadragintus* population at Howden (Chapter 3)
It is important to confirm the results of Bryant's report (2010), and to quantitatively determine whether sufficient mature *E. viminalis* in good condition remain at Howden to support the previously estimated population. If this is the case, other factors may be contributing to the *P. quadragintus* population decline.

Objective 3: Identify the habitat preference of *P. quadragintus* at Howden (Chapter 4)
Identification of the key determining habitat elements that influence the habitat quality for *P. quadragintus* is crucial to develop effective management strategies aimed at improving habitat quality for the species and minimising the risk of extinction of the Howden population.

Objective 4: Examine the possible factors for the decline of *P. quadragintus* populations at Howden (Chapter 5)
Increase visitation of the Reserve resulting in expanding residential and industrial development was considered as one of several factors that may be contributing to the decline in the *P. quadragintus* population. However, a quantitative survey has not been done to understand the impact of the developments and number of visitors.

Chapter 2: *Eucalyptus viminalis* mapping

Eucalyptus viminalis in Peter Murrell Reserve   Photo by Chie Iijima

2.1 Introduction

2.1.1 Characteristics of *Eucalyptus viminalis*

Eucalyptus viminalis (White gum / Manna gum) comprises three main sub-species in Australia, which are *E. viminalis* subsp. *viminalis*, *E. viminalis* subsp. *cygnetensis* and *E. viminalis* subsp. *pryoriana*. Although these three sub-species have an extensive distribution in southeastern Australia, only *E. viminalis* subsp. *viminalis* occurs in Tasmania, including King Island and Flinders Island. Because the study sites were restricted to Tasmania, *E. viminalis* in this report refers to *E. viminalis* subsp. *viminalis*.

E. viminalis is one of the most widespread eucalypt species in Tasmania along with *E. delegatensis*, *E. obliqua*, *E. ovata*, and *E. amygdalina* (Williams & Potts, 1996). It is distributed throughout the north east and eastern half of Tasmania at low altitudes (Figure 2-1) (Phillips *et al.*, 1980; Boland *et al.*, 1984; Duncan & Brown, 1985; Williams *et al.*, 1996). Although *E. viminalis* grows over a wide topographical range from coastal flats to mountains, it attains best development in valleys of hilly and mountainous country, where the soil is moist and at least moderately fertile. *E. viminalis* is predominant at altitudes below 600 m to near sea-level, with the closely related *E. dalrympleana* replacing it at higher altitude (Phillips *et al.*, 1980; Boland *et al.*, 1984; Duncan & Brown, 1985; Cremer, 1990). *E. viminalis* commonly grows to 30-50 m in height and up to 1.5 m in diameter at breast height (DBH), and the crown is usually open and spreading, with drooping branches (Boland *et al.*, 1984). The main flowering period is November to April with a peak in February and March (Williams *et al.*, 1996).

There are 29 native eucalypt species in Tasmania and the Bass Strait islands. All of these native eucalypt species are classified into two subgenera, *Monocalyptus* with 12 species (e.g. *E. amygdalina*, *E. pulchella*, *E. tenuiramis*, *E. obliqua* and *E. regnans*), and *Symphyomyrtus* with 17 species (e.g. *E. viminalis*, *E. ovata* and *E. globulus*). *E. viminalis* rarely forms pure stands, but is usually sub-dominant or co-dominant with other eucalypts from *Monocalyptus* in wet and dry sclerophyll forest. However, it may dominate in grassy and shrubby dry sclerophyll forests and woodlands in drought-prone habitats in south-eastern Tasmania (Williams *et al.*, 1996). Species in *Monocalyptus* and those in *Symphyomyrtus* have evolved different traits to utilise resources such as water. For instance, *E. viminalis* uses deep water, while *E. amygdalina* uses surface water (N. Davidson, personal communication, 2010). [1]TASVEG listed eight vegetation communities in which *E. viminalis* is dominant, sub-dominant and co-dominant in dry sclerophyll and wet sclerophyll vegetation communities (Harris & Kitchener, 2005). In addition, 2 of 8 vegetation communities, *E. viminalis* shrubby/heathy woodland (DVS) and *E. viminalis* wet forest (WVI), are classified as the woodlands/forests which are dominated by *E. viminalis* only. These vegetation communities with brief descriptions are listed below.

- Midlands woodland complex (DMW): These woodlands with dominant tree species of *E. ovata, E. pauciflora* and *E. viminalis* occur on some of the most fertile soils in the lowlands of the Midlands and the lower Derwent River valley.
- *E. ovata* forest and woodland (DOV): *E. ovata* is typically dominant and *E. viminalis* is subdominant or co-dominant at many sites. The community occurs mainly on poorly–drained flats in predominantly lowland areas (< 600 m).
- *E. viminalis* grassy forest and woodland (DVG): *E. viminalis, E. rubida and sometimes E. dalrympleana* are the dominant canopy species in this forest community which attains an open forest of low to medium height (15–25 m). Substrate is dolerite or basalt.
- *E. amygdalina* coastal forest and woodland (DAC): This vegetation community varies from open forest to low, open woodland. *E. amygdalina* is the dominant tree species and forms pure stands of scattered trees. On sites where the sand is less leached, the proportion of *E. viminalis* is generally present as a minor or subdominant species. Substrate is granite, granodiorite or siliceous sediments.
- *E. viminalis–E. globulus* coastal forest and woodland (DVC): *E. viminalis* or *E. globulus* are the dominant tree species, usually 10–20 m tall. *E. amygdalina* or *E. ovata* are sometimes present. This vegetation community occurs in coastal areas. Substrate is coastal sands.
- *E. viminalis* shrubby/heathy woodland (DVS): This community forms woodland with *E. viminalis* as the dominant tree species and shrubby or heathy understorey and few grass species in the ground layer. It most commonly occurs on

[1] The Tasmanian statewide vegetation map. TASVEG produces by the Tasmanian Vegetation Mapping and Monitoring Program (TVMMP) and has defined standard mapping classifications (Department of Primary Industries and Water, 2009)

sands overlying sandstones and mudstones.

- *E. amygdalina* inland forest and woodland on Cainozoic deposits (DAZ): This vegetation community can be dominated by *E. amygdalina*, *E. viminalis*, *E. pauciflora* or occasionally *E. ovata*. It occurs predominantly below 300 m in altitude, and the landform is typically flat or undulating. Substrate is Cainozoic sediments (laterite, sands and gravels) mainly in inland areas.
- *E. viminalis* wet forest (WVI): This community occurs mainly on fertile and well-drained flats. *E. viminalis* as a dominant tree species which can exceed 60 m on fertile sites.

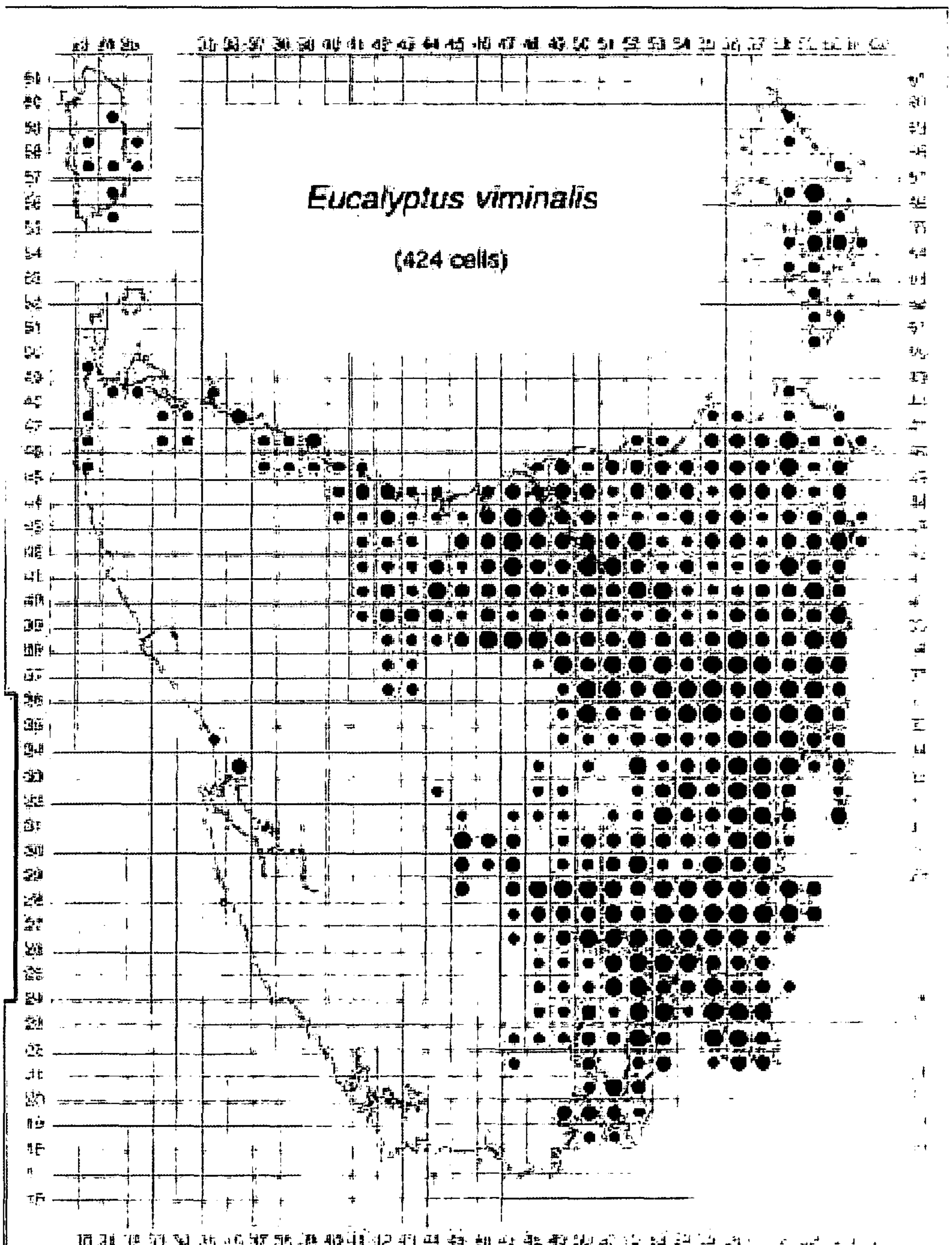


Figure 2-1 Distribution of *E. viminalis* in Tasmania (Williams *et al.*, 1996: 120)

Presence is represented by a dot, the size of which reflects the number of separate sources recording a presence.

•= 1, 2 ●= 3–5 ●= > 5

2.1.2 *E. viminalis* as significant fauna habitat

Several studies have highlighted the significance of *Eucalyptus viminalis* as habitat for fauna species. Hindell and Lee (1987) reported that *E. viminalis* is the most preferred tree species for Koala *Phascolarctos cinereus* among the six eucalypt species in the Brisbane Ranges National Park in Victoria. They found a higher density of koalas in forest where *E. viminalis* was the dominant tree species. Ford (1999) found the *Anthochaera carunculata* (red wattlebird) preferred *E. viminalis* as nesting sites in the Eastwood State Forest in New South Wales. However, while various fauna species have been reported as preferring *E. viminalis*, only one species has been found to be strictly dependent on it. *Pardarotus quadragintus* (forty-spotted pardalote) forages almost exclusively on the foliage of *E. viminalis* as it provides an abundance of energy-rich food for the bird in the form of manna and lerps and suitable foliage size for the bird (Woinarski & Bulman, 1985; Bulman *et al.*, 1986; Dorr, 1999). Manna is a sugary secretion produced from the leaves and twigs of *E. viminalis* in response to insect attacks (Woinarski & Bulman, 1985; Bulman *et al.*, 1986; Dorr, 1999) (Figure 2-2). The high production of manna by this eucalypt gives rise to its common name of Manna Gum. Dorr (1999) found that *E. viminalis* has a higher amount of total nitrogen mg/g dry matter than either *E. obliqua* or *E. globulus*. This may affect the abundance of insects, resulting in a higher level of production of manna (Recher *et al.*, 1996). Lerp is a small white hemispherical cap covering of psyllid nymphs (immature) (Figure 2-2), which is a sap sucking insect from the Psyllidae family. The psyllid nymphs use their straw-like mouthparts to suck plant sap from the phloem vessels of leaves and use the excess starch and sugar, or the honey dew to produce lerps (Dahlsten *et al.*, date unknown). Lerp provides pardalotes and other fauna species with yet another source of energy-rich carbohydrate (Lockwood & Gilroy, 2004) along with manna.

Foliage size is also an important factor to be selected as a suitable habitat for *P. quadragintus*, which rarely hover (Dorr, 1999). The smaller size and narrower shape of *E. viminalis* foliage provide higher accessibility for *P. quadragintus* than the larger and wider *E. obliqua* foliage, allowing *P. quadragintus* to reach the foliage more easily from the perching twigs without hovering (Dorr, 1999). As a consequence, the distribution of *P. quadragintus* is strongly correlated with the distribution of *E. viminalis*.

E. viminalis is not favoured as a commercial timber species because its wood is susceptible to being damaged and to excessive splitting (Cremer, 1990), and it is also regarded as poor quality for firewood. Nevertheless, much of the *E. viminalis* habitat has been cleared for grazing and agriculture and in fact, grassy *E. viminalis* forest in south-east Tasmania has been reduced by greater than 50% since European settlement (Threatened Species Section, 2006). The loss of *E. viminalis* whether in forest situations as dominant, co-dominant or sub-dominant trees, or small remnants in sub-urban regions, has reduced the habitat available to *P. quadragintus* and together with other threats has now species being classed as an endangered species (Bryant, 1992). Extinction of small local populations could also occur as a result of the loss of *E. viminalis* stands. The distribution of *P. quadragintus* is now very restricted in dry sclerophyll forest / woodland, offshore islands, and peninsulas on the east coast of Tasmania (Brereton *et al.*, 1997).

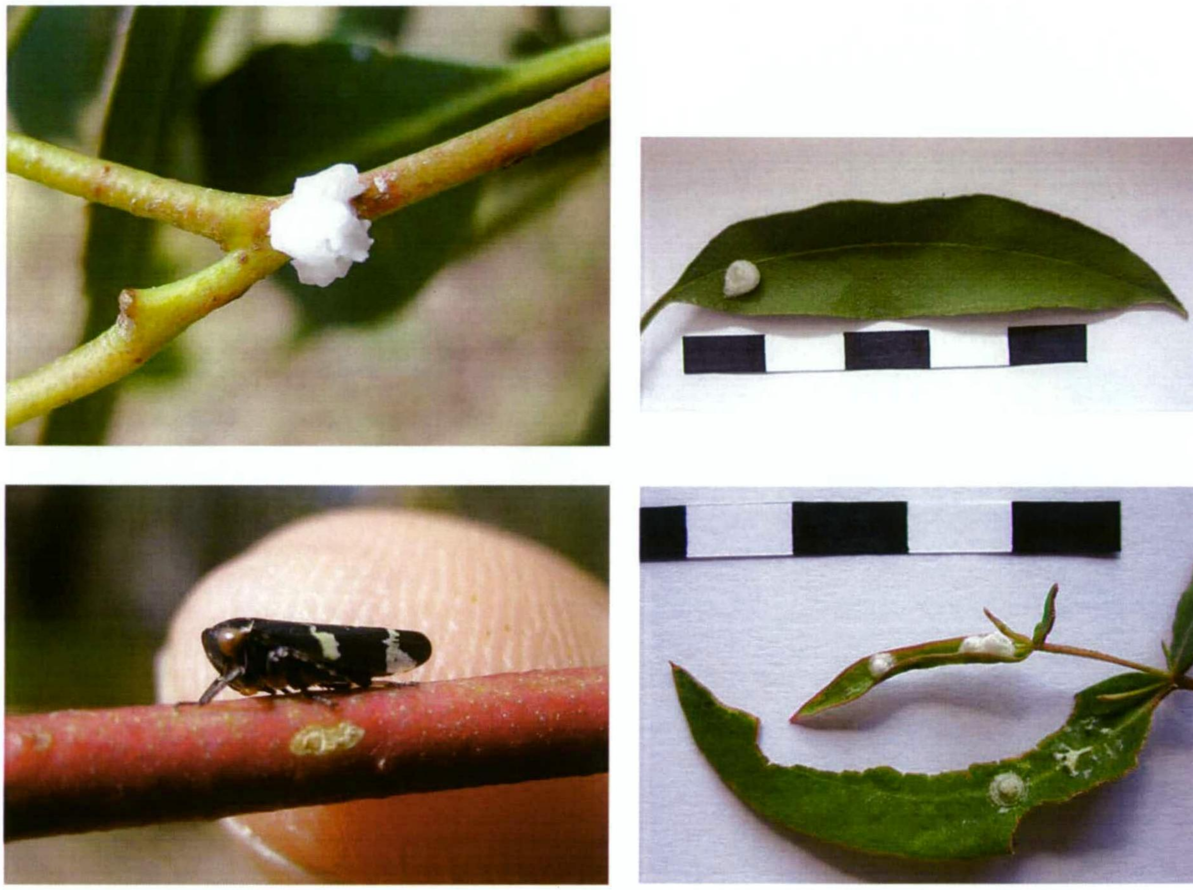


Figure 2-2 (top left) manna formed on an *E. viminalis* twig; (top right) manna formed on an *E. viminalis* leaf; (bottom left) a leaf hopper is the insect that cut the surface of twigs and leaves resulting in the production of manna; (bottom right) lerp formed on *E. viminalis* young leaves
Photo by C. Iijima

2.1.3 Significance for producing *E. viminalis* distribution map

While TASVEG mapping shows the location of vegetation communities dominated by *E. viminalis*. This large scale vegetation map does not provide enough detail to identify the potential habitat for *P. quadragintus*. Brereton *et al.* (1997) found that *P. quadragintus* can use forest or woodland with as little 10% as *E. viminalis* canopy cover. This result shows that the forest or woodland dominated by other eucalypt species with a small number of *E. viminalis* can still retain significant foraging habitat for *P. quadragintus*. Identification of the area size and locations of potential habitat for *P. quadragintus* is important to prioritise future land use planning and management. For example, prescribed burning plans may need to be modified to exclude an area with *E. viminalis* stands, and land development plans may need to be reconsidered before development is commenced. Identification of additional habitat may in fact increase the estimated bird numbers as this figure is calculated based on habitat size.

The main aims of this study are to understand the distribution of *E. viminalis* stands and isolated trees in the Peter Murrell Reserve and Conservation Area and adjacent remnant forests at Howden, and to examine whether these *E. viminalis* stands are a potential habitat for *P. quadragintus*. To assist in classifying *E. viminalis* stands as suitable habitat for *P. quadragintus,* stands were divided into small patches based upon observable changes in vegetation structure and tree size.

2.2 Methodology

2.2.1 Survey area

Location and Land Tenure

The survey was conducted in the Peter Murrell Reserve, the Peter Murrell Conservation Area and adjacent private properties and crown land along the Howden Road and the Channel Highway south of Hobart (Figure 2-3). The Peter Murrell Reserve is located in the Kingborough Municipality, approximately 3 km south of the town of Kingston at the commencement of Tinderbox Peninsula in south east Tasmania. The total area of the Peter Murrell Reserves is 277 ha, which includes the State Reserve (133 ha), Conservation Area (135 ha) and Public Reserve (9 ha) (Figure 2-4). The term 'Reserve' in the following text refers to the State Reserve and Conservation Area. The Reserve has been created from a part of the Huntingfield Estate (approximately 400 ha) purchased by the Tasmanian State Government for housing development and managed by the Department of Community Service and Health (Kirkpatrick & McQuillan, 1996). In 1997, the Peter Murrell Reserve and the Peter Murrell Conservation Area were proclaimed under the *Nature Conservation Act* and have been managed under the *National Parks and Reserve Management Act* (Parks and Wildlife Service, 2006). The surrounding area, however, has been extensively cleared over the last 10 years. There is an industrial estate, school, golf course and call-centre on the western boundary of the Reserve, and residential housing on the north, east and southern boundaries. As a result of this development, isolation of the remnant forest and woodland in the Reserve has been increased, which in turn potentially affects the richness, abundance and structure of native fauna species. There are high levels of public visitation and recreational activities occurring in the Reserve such as walking, dog walking, cycling, horse riding, fishing and trail-bike riding. Although designated areas for these activities are present, including a pony club (25 ha) located within the Conservation Area, along with horse riding and dog walking tracks (Parks and Wildlife Service, 2006), these activities and trail-bike riding have often been observed outside of the permitted areas during the survey. In addition, because of the relatively high risk of uncontrolled bushfire to surrounding residents and the environment, prescribed burns have been carried out for fuel reduction on a regular basis since 1998 (Parks and Wildlife Service, 2006). The other study sites are the Northwestbay Golf Club established in 1965, which is located between Coffee Creek, the Channel Highway, and the Howden Road (Northwestbay Golf Club, date unknown) and the remnant forest (approximately 15 ha) located in the north of the golf course, which is owned by State Government and private landowners. This remnant has a small creek flowing into Coffee

Creek. These study sites also include two private properties along the Howden Road and the narrow strip of crown land along the coast line of Northwest Bay.

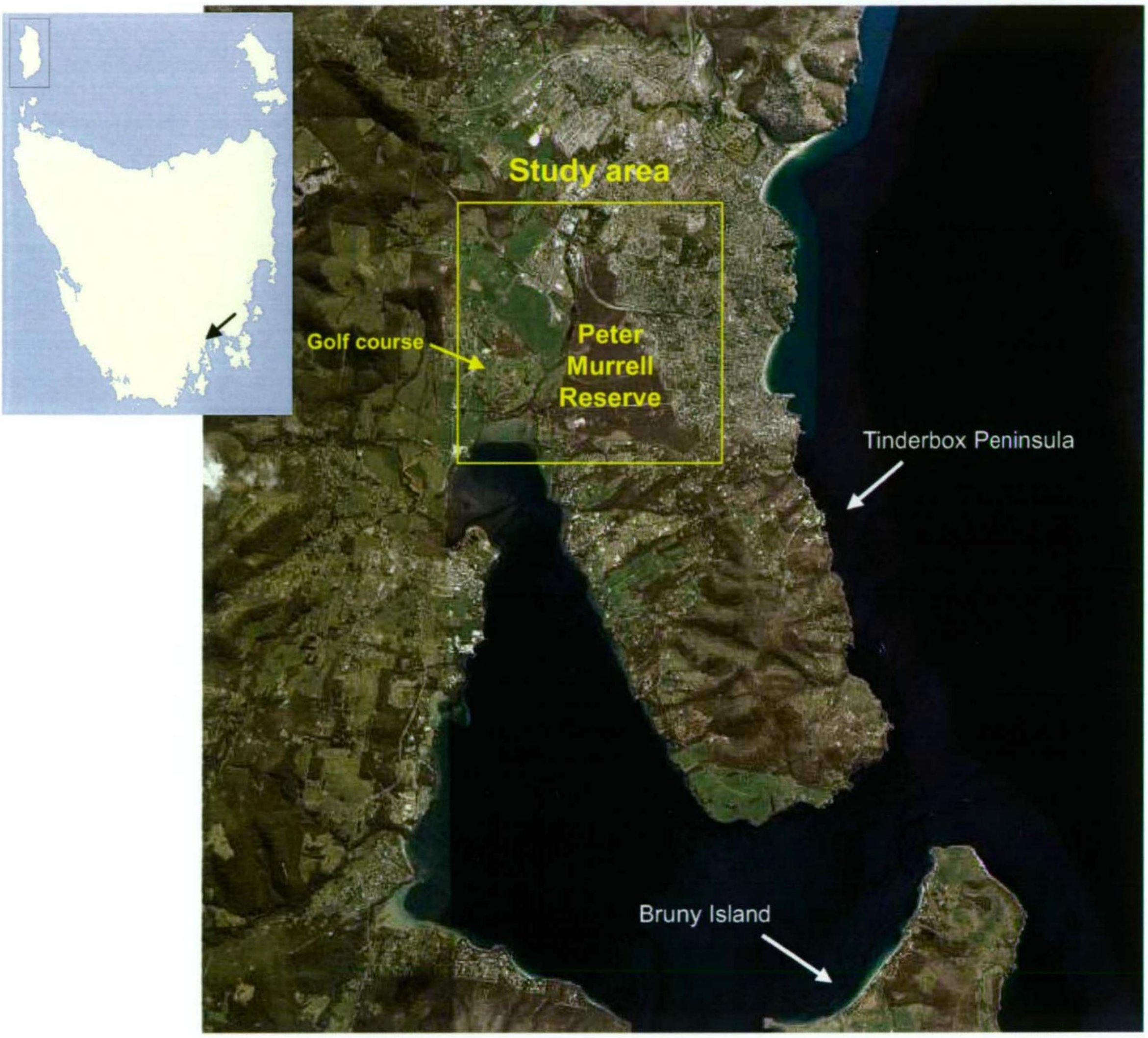


Figure 2-3 Location of the study site (based photo Google Earth, 2005)

Vegetation, soil type and climate

The predominant vegetation type in the Reserve is dry forest and heathland (Parks and Wildlife Service, 2006). Kirkpatrick and McQuillan (1996) categorised nine major vegetation types in the Reserve: 1) *E. amygdalina – E. viminalis – E. obliqua* forest with shrub understorey; 2) *E. ovata* shrubby forest; 3) *E. amygdalina* coastal forest woodland with heath understorey; 4) *E. amygdalina* forest on sandstone with heath understorey; 5) Open heath; 6) Closed heath; 7) Sedgeland; 8) Grassland; and 9) Wetland. The dominant vegetation type in the Reserve is *E. amygdalina* coastal forest and woodland with heath understorey which covers 68% of the Reserve (170 ha). According to this vegetation map, *E. viminalis* mainly occurs within the vegetation type of the *E. amygdalina* - *E. viminalis* - *E. obliqua* forest with shrub understorey, which covers 7 % of the Reserve (17 ha). This vegetation type lies along Coffee Creek, located on the western boundary of the Reserve which creates a narrow corridor of the *E. viminalis* dominant, co-dominant and sub-dominant forest/woodland (Figure 2-5). While the vegetation map produced by Kirkpatrick and McQuillan (1996) does not cover the adjacent study sites, the TASVEG 2.0 (Department of Primary Industries and Water, 2009) shows that the small patches of vegetation in the golf course and the remnant forest between Coffee Creek and the Channel Highway is covered by *E. obliqua* dry forest (DOB), and the crown land along the coast includes *E. viminalis* grassy forest and woodland (DVG), *E. obliqua* dry forest (DOB), and *E. amygdalina* forest and woodland on sandstone (DAS).

No specific climatic data has been recorded for this area. The nearest weather station is situated at Hobart for temperature and Kingston for rainfall. The mean maximum temperature is 17.3 °C and the mean minimum temperature is 8.8 °C (Bureau of Meteorology, 2010a). The mean total annual precipitation is 680.9 mm (Bureau of Meteorology, 2010b). The rock/soil type of the Reserve is predominately siliceous sandstones and siltstones (Calver, 2007). The soils in all study sites (in the Reserve and adjacent forests and woodland) are generally sandy.

2.2.2 Field survey

The *Eucalyptus viminalis* survey was conducted within the Reserve, the Northwestbay Golf Club, private properties and crown land from 31st of March to 30th of June 2010. *E. viminalis* was surveyed by first looking at the most recent vegetation map (Kirkpatrick *et al.*, 1996) and aerial photos (1:10000; TASMAP, 2006) to identify the major location of *E. viminalis* stands and the most likely sites where *E. viminalis* could possibly occur. The above vegetation map was overlain with a black and white aerial photograph (Kirkpatrick *et al.*, 1996) to identify the vegetation communities with *E. viminalis*. Because of difficulties with identifying individual tree species from aerial photographs, it is possible that small *E. viminalis* stands and isolated individual trees are present outside the vegetation community of *E. amygdalina* – *E. viminalis* – *E. obliqua* forest. Therefore a ground survey was undertaken by walking on tracks and off track to cover the entire Reserve in order to identify any additional *E. viminalis* stands and individual trees. The locations of additional trees were recorded individually using the Global Positioning System (GPS) with accuracy between 5 and 10 m. The newly described *E. viminalis* stands and the previously known *E. viminalis* stands along Coffee Creek, were segmented into smaller patches based upon the changes in vegetation structure, *E. viminalis* tree size and existing cleared edges between forest patches containing *E. viminalis*, such as fire trails, roads and cleared land. Because of the successional change of the *E. viminalis* density and vegetation communities, some of the boundaries between the patches are not very clear (Appendix 1). The boundaries of each patch were determined by walking the edges of identified areas and utilising the tracking ability of the

GPS (which automatically records movement). Additional boundaries were determined from existing roads and fire trails.

Trees more than 15 cm in DBH (diameter at breast height) in each patch were randomly selected for surveying. All large *E. viminalis* trees exceeding 90 cm in DBH, were surveyed and plotted by GPS. The rationale for selecting trees exceeding 90 cm in DBH was that trees with more than 2.80 m in circumference (= approximately 90 cm in DBH) are recognised as large trees potentially providing nesting habitat for *P. quadragintus* (Bryant, 2010). All trees were classified into 4 classes by DBH: Class 1 = 15-30 cm; Class 2 = 30-45 cm; Class 3 = 45-90 cm; and Class 4 = >90 cm. *E. viminalis* canopy cover was recorded by observation from the ground, which is also important to assess the habitat for *P. quadragintus*. The previous study suggested that forest and woodland with 10 % or more canopy coverage is critical as habitat for the species (Brereton *et al.*, 1997). Other variables recorded included tree DBH, tree height, and *E. viminalis* canopy conditions. These additional variables are discussed in Chapter 4.

The vegetation structure and environment survey were conducted at each forest patch containing *E. viminalis* to describe the attributes of each patch. Dominant plant species and the percentage cover in each vegetation layer were recorded by observation from the ground to observe the whole area of each patch according to the following classes: under storey = 0–1.5 m; midstorey = 1.5–10 m; and canopy = more than 10 m in height. The percentage cover of dominant surface type (e.g. leaf litter, bare soil, rock, vegetation and water surface) was also recorded. Other environmental variables noted included the evidence of fire, soil types, aspect, and presence of weed species.

2.2.3 *E. viminalis* mapping

An *E. viminalis* map was produced using the computer software MapInfo. The GPS data was overlaid on the TASMAP aerial photograph for the Hobart region (circa late 1990s up to 2005) with a grid reference of GDA94/55. The Reserve boundary, fire trails and walking tracks were also acquired from the TASMAP.

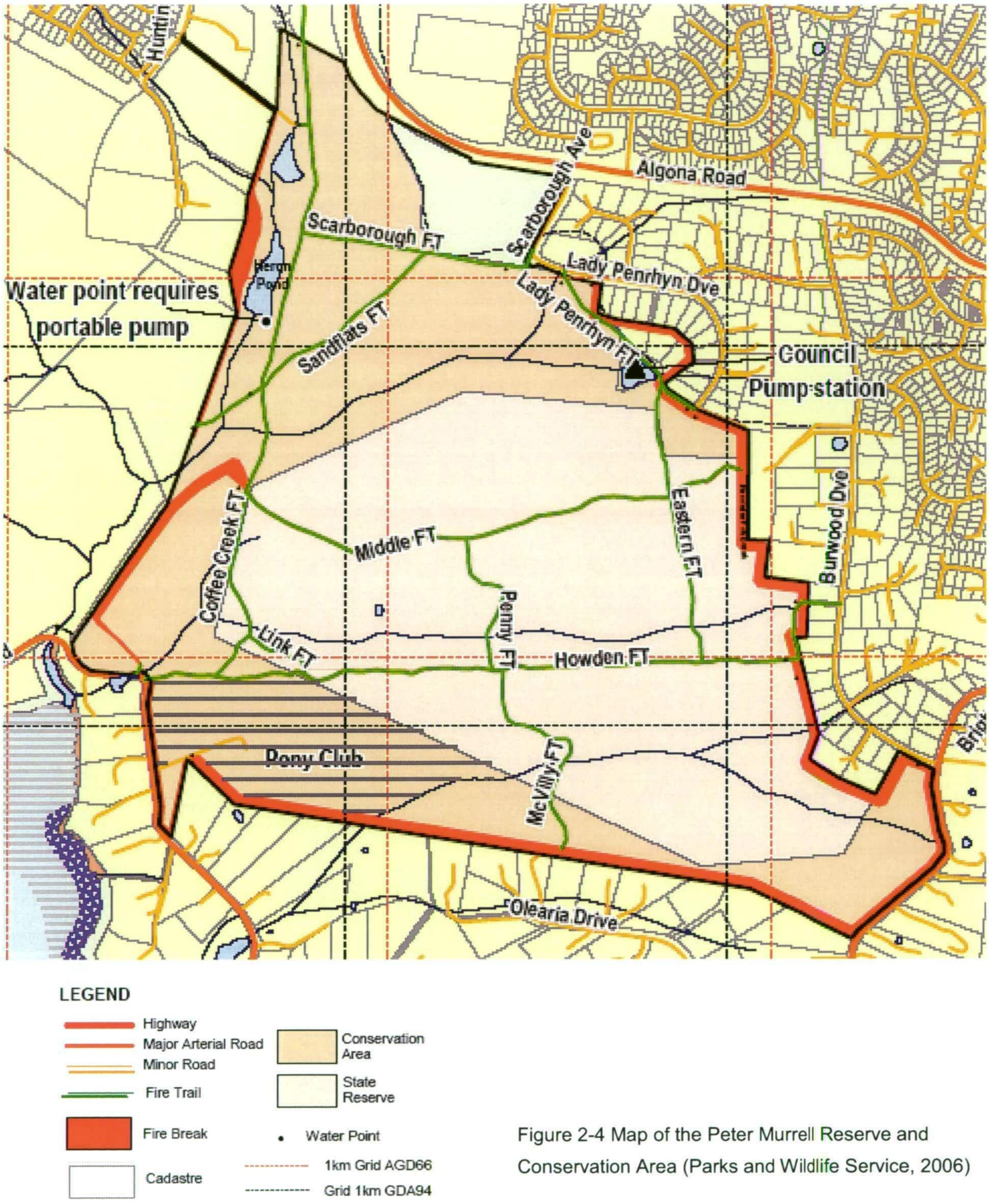
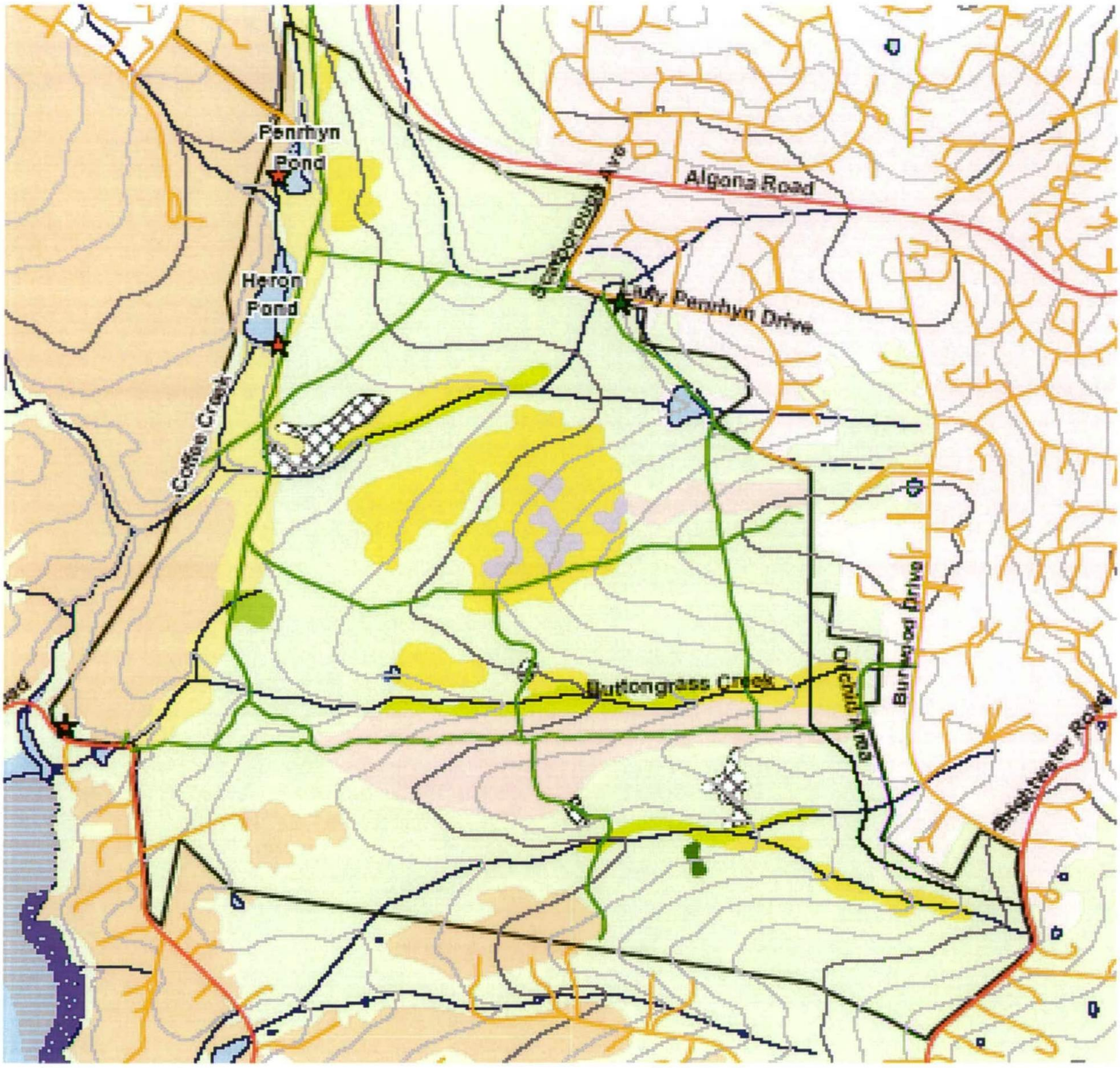


Figure 2-4 Map of the Peter Murrell Reserve and Conservation Area (Parks and Wildlife Service, 2006)



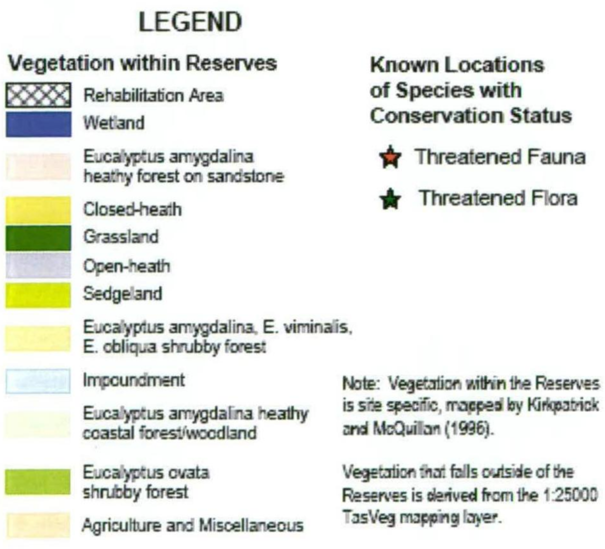


Figure 2-5 Vegetation map in the Peter Murrell Reserve and Conservation Area (Parks and Wildlife Service. 2006)

2.3 Results

2.3.1 Location of *E. viminalis* stands and isolated trees

From the *E. viminalis* distribution survey, a total 39.86 ha of *E. viminalis* stands and 72 large isolated trees were identified in the Reserve and adjacent remnant forests (Table 2-1). All of the *E. viminalis* stands and isolated trees were divided into 3 areas based upon their spatial distribution: Area 1 (along Coffee Creek); Area 2 (mid-eastern section of the Reserve); and Area 3 (the remnant forest between Coffee Creek and the Channel Highway including the Northwestbay Golf Club) (Figure 2-6). Area 1 includes the previously documented *E. viminalis* stands (as shown in the previous vegetation map). However, *E. viminalis* stands in Area 2 and 3 are newly identified for the purpose of the *P. quadragintus* study.

A total of 954 *E. viminalis* trees were surveyed, which included 318 trees in Class 1 (DBH 15-30 cm), 209 trees in Class 2 (DBH 30-45 cm), 284 trees in Class 3 (DBH 45-90 cm), and 143 trees in Class 4 (DBH > 90 cm). Almost all Class 4 trees occur along the western side of the Coffee Creek Fire Trail and grow close to water sources, such as Coffee Creek and Penrhyn Pond and Heron Pond. A high density of Class 4 trees was also recorded in the remnant patch between Coffee Creek and the Channel Highway and in the golf course (Figure 2-7). In addition, *E. viminalis* stands were found either as pure stands, subdominant and co-dominant with *E. amygdalina*, *E. ovata*, *E. obliqua* and/or *E. globulus*. In particular, *E. amygdalina* and *E. obliqua* were recorded as the major co-dominant canopy species (Table 2-1).

Figure 2-6 *E. viminalis* distribution area map in the Reserve and adjacent area

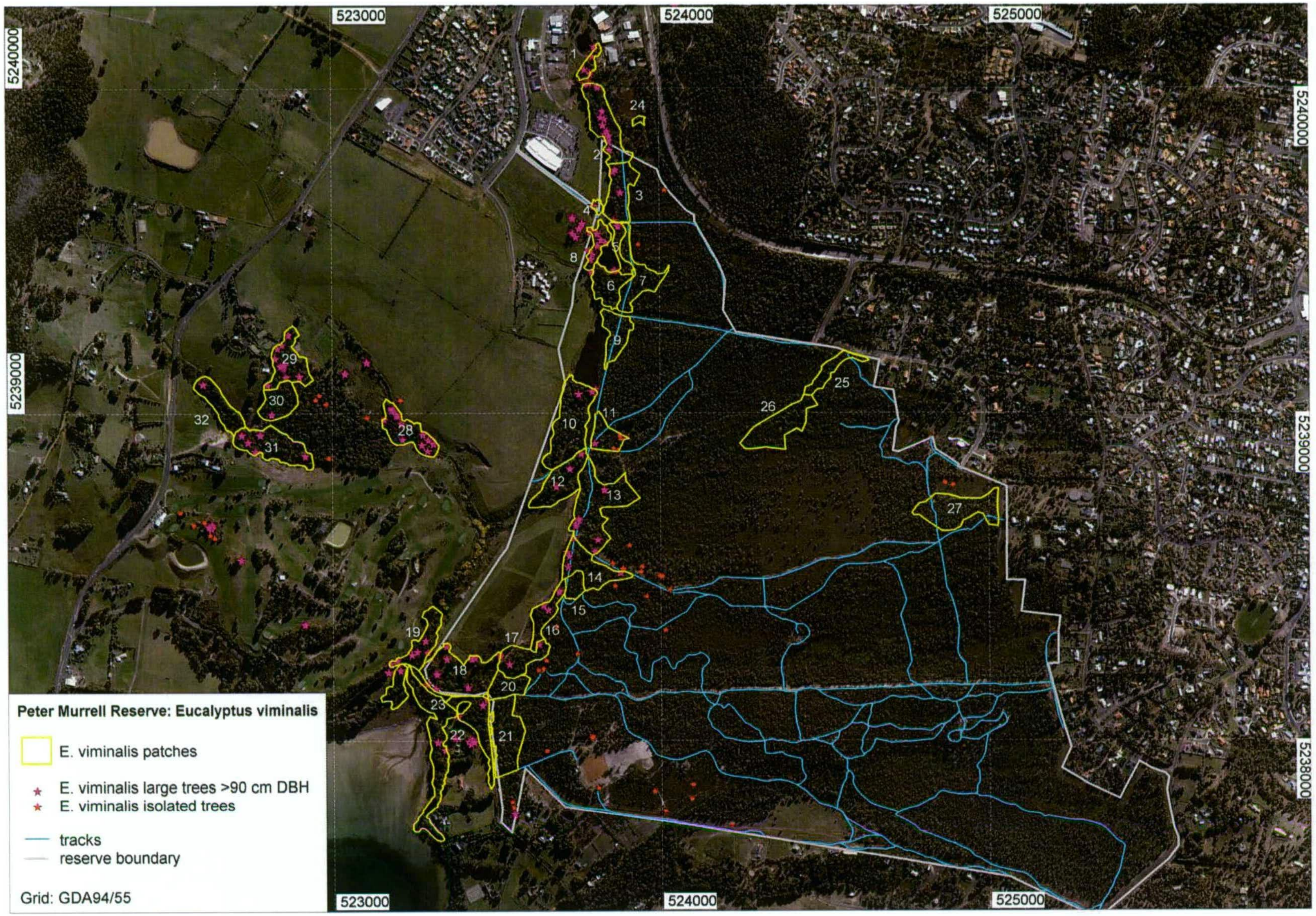


Figure 2-7 Forest patches containing *E. viminalis* and isolated tree map in the Reserve and adjacent area

2.3.2 Summary of forest patches containing *E. viminalis*

Location of patches

The forest vegetation containing *E. viminalis* was divided into 32 patches based upon observable changes in vegetation structure and tree size or cleared edges (Figure 2-7). The aggregate area of the 32 patches is 39.86 ha and patch sizes vary from 0.08 ha (patch number 24) to 2.95 ha (patch number 23). Twenty-four patches (1 to 24) with a total patch size of 29.07 ha were located in Area 1. This includes 6 patches (1, 2, 19, 22, 23 and 24) which are outside the formal boundary of the Reserve. Three patches (25 to 27) were located in Area 2 with a total patch size of 4.29 ha. Five patches (28 to 32) were located in Area 3 and the total patch size is 6.5ha. The patches in Area 1 are referred to as the Coffee Creek group; the patches in Area 2 referred to as the Mid-eastern group; and the patches in Area 3 are referred to as the Channel Highway group (Table 2-1, Figure 2-6). Individual patch details are shown in Appendix 2.

E. viminalis canopy cover

The Coffee Creek group showed the highest mean *E. viminalis* canopy cover with 56 %, followed by the Channel Highway group with 40 %. The lowest *E. viminalis* canopy cover was found in the Mid-eastern group with 36.7 % (Table 2-1). All 32 patches have an *E. viminalis* canopy cover exceeding 10 %, except number 11 with only 5 %. The highest canopy cover of *E. viminalis* was recorded at number 1 with 95 %, followed by number 24 with 90 %, and number 3 and 6 with 85 % (Figure 2-8).

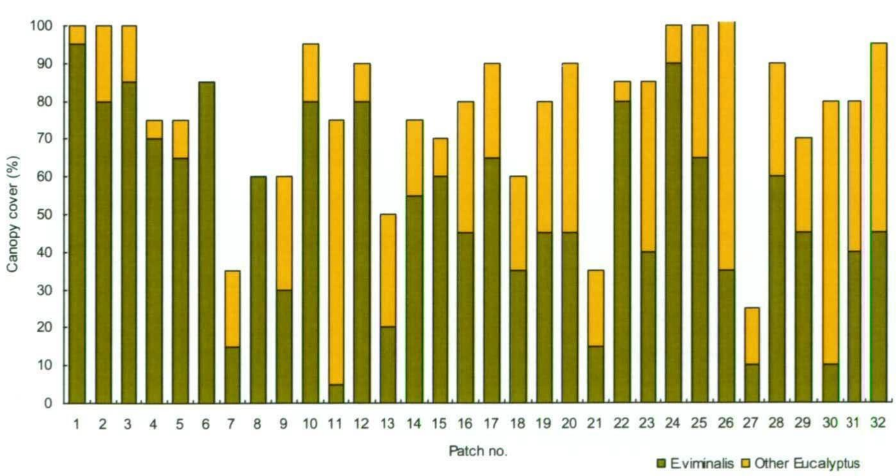


Figure 2-8 Canopy cover (%) of *E. viminalis* and other *Eucalyptus* species in each patch in Howden.

All of the patches, except patches 6 and 8, which comprised pure *E. viminalis* stands, white gum occurred as ca o-dominant or sub-dominant tree with *E. amygdalina*, *E. ovata*, *E. obliqua* and/or *E. globulus*. However, patches 1, 4 and 22 included only 5 % of other *Eucalyptus* canopy cover. As a co-dominant and sub-dominant canopy species, *E. amygdalina* showed the highest frequency rate of 71.9 %, while *E. obliqua* showed the highest mean canopy cover of 22.6 % in total. *E. obliqua* occurred at all of the patches in the Channel Highway group and showed a significantly higher mean canopy cover (32 %) compared to the Coffee Creek group (7.9 %) and Mid-eastern group (11.67 %). *E. ovata* occurred only in 5 patches (3, 4, 22, 25, and 26) contributing 5 % canopy cover, except in one patch number 25 with 20 % canopy cover. *E. globulus* occurred only in patch number 32 contributing only 5 % cover (Table 2-1).

Table 2-1 Patch size and canopy cover

Patch Group	Patchno.	Area (ha)	Canopy cover (%)					
			E.viminalis	Other Eucalyptus				
				E. amygdalina	*E. obliqua*	*E. ovata*	*E.globulus*	Total
Coffe Creek	1	**0.31**	95	5	0	0	0	5
	2	1.63	80	10	10	0	0	20
	3	1.27	85	5	5	5	0	15
	4	**0.11**	70	0	0	5	0	5
	5	**0.45**	65	10	0	0	0	10
	6	**0.97**	85	0	0	0	0	0
	7	1.30	15	20	0	0	0	20
	8	**0.57**	60	0	0	0	0	0
	9	**0.96**	30	30	0	0	0	30
	10	2.43	80	15	0	0	0	15
	11	**0.73**	5	70	0	0	0	70
	12	1.44	80	5	5	0	0	10
	13	2.83	20	30	0	0	0	30
	14	1.39	55	5	15	0	0	20
	15	**0.40**	60	5	5	0	0	10
	16	**0.80**	45	35	0	0	0	35
	17	**0.99**	65	25	0	0	0	25
	18	2.51	35	0	25	0	0	25
	19	1.05	45	0	35	0	0	35
	20	**0.73**	45	5	40	0	0	45
	21	1.89	15	15	5	0	0	20
	22	1.25	80	0	0	5	0	5
	23	2.95	40	5	40	0	0	45
	24	**0.08**	90	5	5	0	0	10
	Total	29.07						
	Mean	1.21	56.0	12.5	7.9	0.6	0.0	21.0
Mid-eastern	25	**0.62**	65	15	0	20	0	35
	26	1.68	35	30	35	5	0	70
	27	1.99	10	15	0	0	0	15
	Total	4.29						
	Mean	1.43	36.67	20.00	11.67	8.33	0.00	40.00
Channel Highway	28	1.30	60	0	30	0	0	30
	29	1.37	45	10	15	0	0	25
	30	1.00	10	40	30	0	0	70
	31	1.79	40	0	40	0	0	40
	32	1.04	45	0	45	0	5	50
	Total	6.50						
	Mean	1.30	40.00	10.00	32.00	0.00	1.00	43.00
	Total	**39.86**						
	Mean	**1.25**	**51.7**	**17.8**	**22.6**	**8.0**	**5.0**	**26.3**
	Frequency (%)		**32 (100)**	**23 (71.9)**	**17 (53.1)**	**5 (15.6)**	**1 (3.1)**	**32 (100)**

The highest number of Class 4 trees (DBH > 90 cm) was recorded at the Coffee Creek group with 90 trees, followed by the Channel Highway group. However, the Channel Highway group has a higher density of Class 4 trees (4.6 trees / ha) than the Coffee Creek group (3.1 trees / ha). No Class 4 tree was recorded in the Mid-eastern group (Table 2-2).

Table 2-2 Number of Class 4 trees at 3 patch groups

	Number of Class 4 tree	Number of Class 4 trees/ha
Coffee Creek	90	3.1
Mid-east	0	0
Channel Highway	30	4.6

The patches with the highest number of Class 4 trees were patch number 2 with 14 trees, followed by patches 28 with 13 trees, and patch number 29 with 10 trees. In contrast, Class 4 trees were not identified in 9 patches (7, 9, 15, 20, 21, 24, 25, 26, and 27), which includes all 3 patches of the Mid-eastern group. (Figure 2-9). Class 4 trees were also found outside the patches, especially in the golf course and the cleared land adjacent to patch number 8. Most of the Class 4 trees were recorded on cleared land, such as on the golf course and along the driveway to a private residences and paddocks in the private properties (between patches 22 and 23) (Figure 2-7).

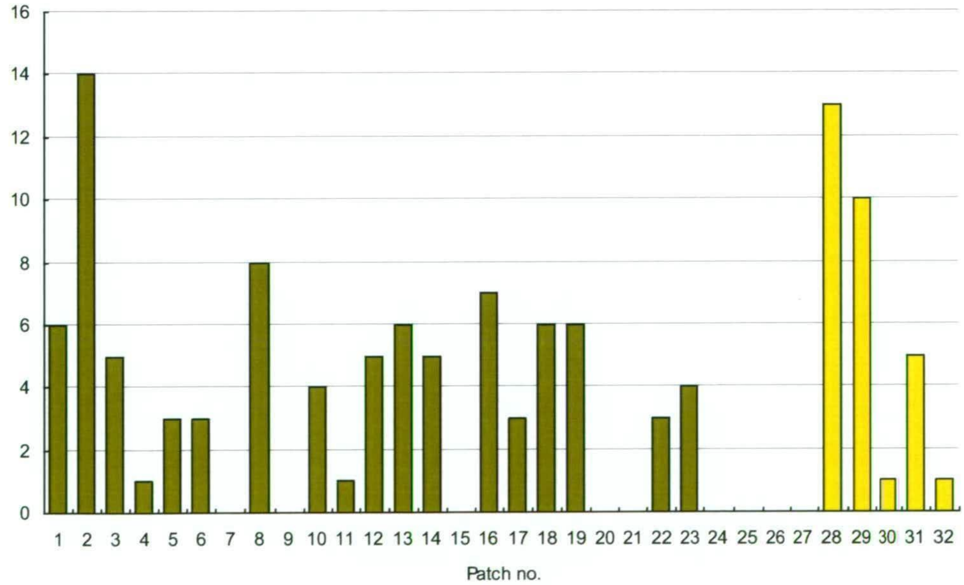


Figure 2-9 Number and distribution of Class 4 *E. viminalis* trees

Green bar: the Coffee Creek group, Yellow bar: the Channel Highway group. No Class 4 trees were recorded in the Mid-eastern group.

E. viminalis vegetation structure

At all three patch groups, the plant species with the highest mean cover at each layer were the same species: *E. viminalis* as the canopy tree species, *Melaleuca squarrosa* as the midstorey species, and *Pteridium esculentum* as the understorey species. While the dominant vegetation species at each level in the vegetation structure was consistent between different sites, there were substantial differences in the actual coverage of species between individual patch groups. The distinctiveness of the high mean coverage was different at each patch group. *M. squarrosa* showed a significantly high mean cover in the Mid-eastern group with 42.5 %, while *M. squarrosa* was only slightly higher than *Acacia melanoxylon* in the Coffee Creek group, and *Exocarpos cupressiformis* in the Channel Highway group. For the understorey plant species, *Pteridium esculentum* showed significantly high mean cover (68 %) and frequency rate (97 %). The mean cover of *P. esculentum* was the most significant in the Coffee Creek group (81.3 %) compared with the other two groups. In the Coffee Creek group, 20 patches (83 %) were recorded with more than 60 % coverage of *P. esculentum* (Appendix 3).In contrast, in the Mid-eastern group, the mean cover of *P. esculentum* (21.7 %) was not significant and *P. esculentum* was co-dominated with *Gleichenia dicarpa* (17.5 %) and *Lomandra longifolia* (15.0 %) (Table 2-3). All of the dominant plant species at each patch shows in Appendix 3

Table 2-3 Dominant plant species in each vegetation layer at all 3 patch groups

	Coffee Creek			Mid-eastern			Channel Highway			All patches		
	Mean (%)	Frequency		Mean (%)	Frequency		Mean (%)	Frequency		Mean (%)	Frequency	
Canopy												
E. amygdalina	16.7	18	75%	20.0	3	**100%**	25.0	2	40%	12.8	23	72%
E. obliqua	17.3	11	46%	35.0	1	33%	32.0	5	**100%**	12.0	17	3%
E. viminalis	**56.0**	24	**100%**	**36.7**	3	**100%**	**40.0**	5	**100%**	51.7	32	100%
Middle storey												
Acacia melanoxylon	14.0	21	**88%**	10.0	2	**67%**	5.3	3	60%	10.3	26	81%
Allocasuarina monilifera	0.0	0	0%	10.0	1	33%	0.0	0	0%	0.3	1	3%
E. viminalis	5.4	13	54%	0.0	0	0%	10.0	1	20%	2.5	14	44%
Exocarpos cupressiformis	7.6	5	21%	10.0	1	33%	9.0	4	**80%**	2.6	10	31%
Melaleuca squarrosa	**16.8**	14	58%	**42.5**	2	**67%**	**10.0**	1	20%	10.3	17	53%
Understorey												
Dianella tasmanica	6.3	4	17%	5.0	1	33%	4.0	2	40%	1.2	7	22%
Gleichenia dicarpa	0.0	0	0%	17.5	2	67%	0.0	0	0%	1.1	2	6%
Lepidosperma spp.	5.0	1	4%	0.0	0	0%	10.0	1	20%	0.5	2	6%
Leptospermum scoparium	8.8	4	17%	5.0	2	67%	40.0	1	20%	2.7	7	22%
Lomandra longifolia	4.9	14	58%	15.0	2	67%	0.0	0	0%	3.1	16	50%
Pteridium esculentum	**81.3**	23	**96%**	**21.7**	3	**100%**	**48.0**	5	**100%**	68.0	31	97%

2.4 Discussion

2.4.1 Summary of the previous records of *P. quadragintus*

The results of this study show that *E. viminalis* stands were mainly distributed in Area 1 (Coffee Creek), which confirms the previously known foraging habitat for *P. quadragintus*. As a result of this correlation, a number of field studies have been undertaken to determine population (Threatened Species Unit, 1998; Bryant, 2010) and foraging behaviour of the species in this area (Dorr, 1999). The total area size of *E. viminalis* stands in Area 1 is 29 ha, while the previous study (Bryant, 1995) suggested that the suitable habitat for *P. quadragintus* was 12 ha along Coffee Creek. The reason for the difference in the habitat size is probably due to the fact that a comprehensive survey of *E. viminalis* has not previously been undertaken. A closer survey of the 29 ha in Area 1 will examine how much of this area is actual habitat for *P. quadragintus* as discussed in Chapter 4. The highest human disturbance occurs in Area 1. In the Reserve, a variety of recreational activities, such as horse riding, on and off leash dog walking, trail bike riding, cycling, and walking occur frequently. These activities are not confined to the designated recreation areas, but occur frequently in prohibited areas (e.g. off leash dog walking and trail bike riding). Although *P. quadragintus* were often observed at the car park at Penrhyn Pond (S. Bryant, personal communication, 2010) – which might imply some types of human activities, such as driving and walking, do not negatively impact their occurrence – the noise, such as from trail bike riding and dog barking may contribute to making the habitat unsuitable for the species. The effects of human disturbance on the *P. quadragintus* population will be discussed in Chapter 5.

Area 2 can be separated into two sites, a northern site and a southern site, based upon the absence of *E. viminalis* trees between the two sites. The both sites containing *E. viminalis* were found as new additional *E. viminalis* stands and no *P. quadragintus* survey has previously been conducted at these sites. The reason for no previous identification of *E. viminalis* stands in Area 2 is probably due to low accessibility to this area, especially the stands in the northern site where there is no clear walking track. This implies that the area has few disturbances from recreational activities. According to the latest *P. quadragintus* survey report (Bryant, 2010), the birds were observed several times on the Sandflats Fire Trail in summer, which is located between Area 1 and the northern site of Area 2, although even isolated *E. viminalis* trees were not present in that section. This might suggest that *P. quadragintus* use Area 2 for foraging habitat and were observed while they were traveling between Area 1 and 2 (Figure 2-10).

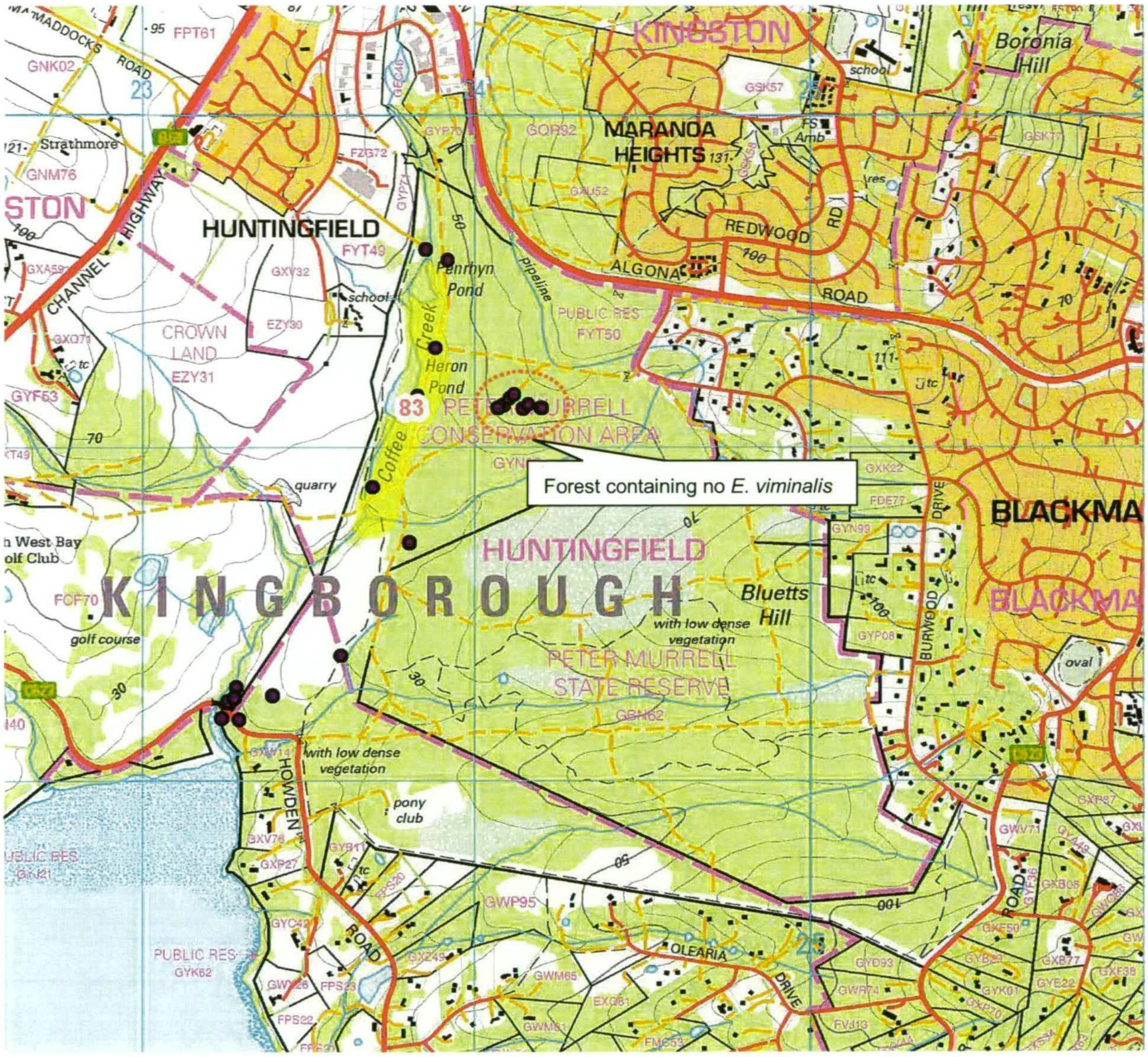


Figure 2-10 *P. quadragintus* survey spring/summer 2009 - 2010 at Howden (Bryant, 2010)

There has been no *P. quadragintus* survey in Area 3. The area surrounding this remnant forest has been heavily cleared with no continuous vegetation remaining between the remnant forest and Area 1 (approximately 500 m). However, a small creek flows into Coffee Creek which could be a potential corridor for *P. quadragintus* to move between Area 1 and Area 3. A winter flock of 6 to 12 birds was reported in Area 3 by Peter Brown (Bryant, 1997). In winter *P. quadragintus*, particularly juveniles, disperse more widely, expanding to an area probably ten times as large as the habitat of breeding pairs (Hinton *et al.*, 1981). The Northwestbay Golf Club also contains some small remnant forest and isolated Class 4 *E. viminalis* trees. *P. quadragintus* is known from this area (S. Brown, personal communication) and probably uses these small remnants and isolated trees as 'stepping stones' to travel between Area 1 and 3.

2.4.2 Distribution of Class 4 *E .viminalis*

While *P. quadragintus* use stumps, fallen trees or limbs, and occasionally holes in the ground for nesting sites (Woinarski & Rounsevell 1983; Woinarski & Bulman 1985; Brown 1986), the presence of Class 4 *E. viminalis* in their habitat is critical, because these trees are more likely to have hollows and produce large fallen limbs. The result of the survey showed the locations of Class 4 trees were concentrated close to a water source, such as adjacent to Coffee Creek and the western bank of Penrhyn Pond in Area 1, and two small creeks in Area 3. Class 4 trees also occur at the edge of the forest and in the middle of cleared land. Although there are many factors affecting plant growth (Fensham, 1989), one of the possible reasons for the increased number of Class 4 trees growing along the margin of the forest in Area 1 is that the soils contained in the areas of cleared land have been enhanced due to fertilization from horse droppings (along the horse riding trail) and increased amount of runoff water from the hardened horse riding track. In Area 3 the surrounding cleared land is used for sheep and cattle grazing, which also provides higher levels of nutrients to the edge of the remnants. The other possible reason is that the canopies of the trees at the edge of forest or in the middle of the cleared land are more spreading due to the availability of a wider space. The trees with spreading canopies attract vertebrate animals and birds for their roosting and nesting sites, thereby the soils beneath these trees are likely to be enriched by the droppings and urine of animals and birds (Kirkpatrick, 1997).

2.4.3 Habitat suitability for *P. quadragintus*

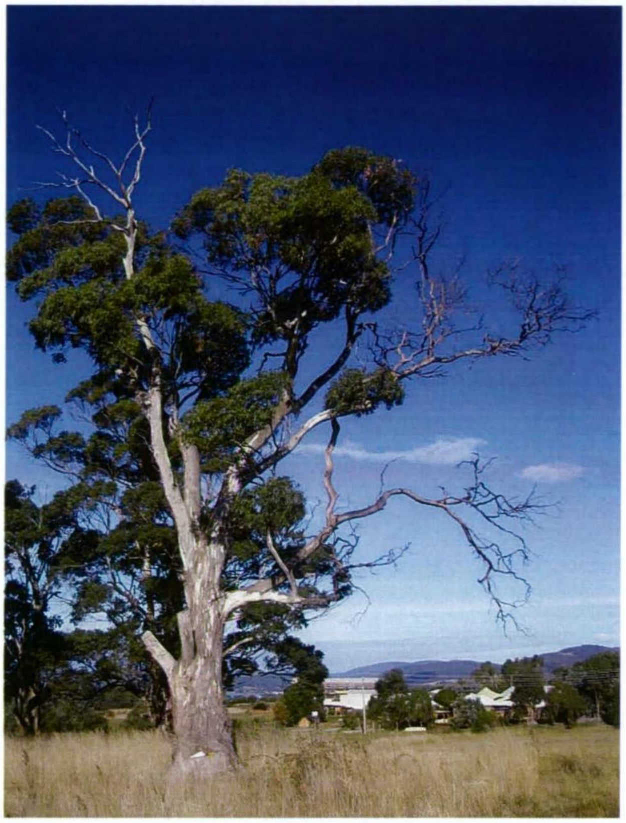
E. viminalis canopy coverage is one of the most important factors to assess the forest as potential habitat for *P. quadragintus* due to their great dependence upon *E. viminalis*. Bereton *et al.* (1997) found that *P. quadragintus* was only recorded in forests where the *E. viminalis* canopy was 10 % or higher. All patches, except patch number 11 in the Coffee Creek group, have more than 10 % *E. viminalis* canopy cover.

The field survey shows the *E. viminalis* patches consist of either pure *E. viminalis* stands or a proportion mixed with other eucalypts species, such as *E. amygdalina* and *E. obliqua* in most of the patches. According to Brereton *et al.* (1997), five specific vegetation communities are potentially suitable habitat for *P. quadragintus*; 1) *E. viminalis* coastal shrubby forest on Holocene sand; 2) Dry *E. obliqua* forest; 3) *E. pulchella – E. globules – E. viminalis* grassy shrubby dry sclerophyll forest; 4) *E. viminalis* grassy forest; and 5) *E. ovata – E. viminalis* forest. These vegetation communities did not include the vegetation communities' dominant or co-dominant in *E. amygdalina*, which was the most common tree species in most of the *E. viminalis* patches in the study area. However, Tinderbox Peninsula, the closest habitat for the *P. quadragintus* colony to Howden, also has *E. amygdalina* as the most common tree species, along with *E. viminalis* (Hinton *et al.*, 1981).

Class 4 trees are a key habitat quality characteristic driving territory size and density of birds. A minimum of two Class 4 *E. viminalis* trees within a 20 tree cluster hypothetically can sustain one breeding pair of *P. quadragintus* (Bryant, 2010). Because the total number of trees in each patch was not counted in this study, it is not possible to assess the potential number of breeding pairs of birds in each patch using the same methods. However, the position and density of Class 4 trees can provide an idea of the potential breeding habitat. The Coffee Creek group was previously known as breeding habitat, although the specific nesting sites were not officially documented. The Mid-eastern group has no Class 4 tree, thereby the 3 patches in this group have a low possibility of providing breeding habitat. On the other hand, the patches in the Channel Highway group, specifically patches 28 and 29, include a high density of Class 4 trees. While the bird observation record was made only in winter, some of the patches in this group have potential to sustain breeding pairs of birds. During this study period, bird surveys were conducted in September (the early breeding season) and *P. quadragintus* was detected in the Channel Highway group (Chapter 4).

The dominant plant species and mean coverage of *Melaleuca squarrosa* in the midstorey and *Pteridium esculentum* in the understorey showed similarities between the Coffee Creek group and the Channel Highway group, but a difference with the Mid-eastern group. Mean coverage of *M. squarrosa* was higher in the Mid-eastern group than the other two groups, while the result of the mean coverage of *Pteridium esculentum* was reversed. The differences of the Mid-eastern group from the other two groups were driven by patch no.25 and 26. These two patches indicate a wetter environment than other patches, because *P. esculentum* occurs in well-drained soils of most vegetation types (Garrett, 1996), while *M. squarrosa* forms extensive colonies in wetter areas (Whiting *et al.*, 2004). In addition, *Gleichenia dicarpa* as a common fern species in a heathland on poorly drained soils and watercourse margins (Garrett, 1996), occurs only in patch number 25 with a higher coverage than *P. esculentum.* While past reports identified dry sclerophyll forest and woodland with *E. viminalis* as habitat for *P. quadragintus,* they did not specify if *E. viminalis* stands in a wetter environment were suitable habitat.

Chapter 3: *Eucalyptus viminalis* crown condition assessment



E. viminalis in cleared land adjacent to Peter Murrell Reserve
Photo by Chie Iijima

3.1 Introduction

3.1.1 Eucalypt decline and causal factors

Eucalypt decline has increased dramatically throughout Australia and has been recognised as a serious issue for degrading biodiversity by changing the forest/woodland ecosystem (Jurskis, 2005). Eucalypt decline and dieback has serious consequences for foliage gleaning bird species. *P. quadragintus* is especially vulnerable to decline in *E. viminalis* health because of their two attributes; 1) preference for foraging on *E. viminalis* foliage; and 2) limited dispersal ability. Limited dispersal ability of *P. quadragintus* is probably due to an insufficient morphological adaptation to prolonged flight, unlike the *Pardalotus striatus* (striated pardalote) and *Pardalote punctatus* (spotted pardalote). In Tasmania *P. striatus* migrate to overwinter on the Australian mainland and *P. punctatus* may also disperse over long distances (Woinarski & Bulman, 1985). A number of studies have been undertaken to identify the causes of eucalypt decline and dieback. These studies seek to identify and solve problems associated with dieback for the purpose of ecosystem conservation and forest management within pastoral, agricultural and plantation landscapes (Podger *et al.*, 1980; Kile *et al*,. 1981; Stone *et al.*, 2003; Davidson *et al.*, 2007; Stone *et al.*, 2008). The typical symptoms of eucalypt dieback commence with poorly-developed crowns and sparse foliage followed by an increasing proportion of dead twigs and branches accompanied by epicormic growth (Landsberg & Wylie, 1983; Stone, 1999; Turner & Lambert, 2005). As the process continues, epicormic growth comprises a larger proportion of the foliage and crown thinning and significant dead branches occur. The final stage of dieback is crown and tree death (Turner & Lambert, 2005). The key attribute of eucalypt dieback is crown dieback. Stone (1999: 52) defined crown dieback as "the development of symptoms associated with the unnatural mortality of leaves, buds and branches". A variety of factors, such as vertebrate and invertebrate browsing, climatic stress especially drought, excessive or deficient fire regime, disease, grazing pressure, and aggressive bird species, can reduce eucalypt tree health. The complex interaction of these biotic and abiotic factors often causes eucalypt decline and dieback (Stone, 1999). Some of the causal factors are discussed below.

Drought

Drought has been considered as one of the major causes of eucalypt dieback and death of native trees (Landsberg, 1985). However, several studies found no evidence that this is the primary cause of dieback, but drought does tend to exacerbate dieback (Landsberg, 1985; Turner & Lambert, 2005) by making trees more susceptible to fungal infection and insect defoliation in dieback disease (Podger *et al.*, 1980). However, a study (Grice, 1995) conducted in Tasmania found that eucalypt dieback has been concentrated in the areas with lowest rainfall and drought is considered to be the major cause of eucalypt decline in that state (Neyland, 1996). In Queensland, Fensham (1998) found drought causes a decline in the tree basal area and tree condition exhibited by many trees that had entirely lost their crown foliage.

Invertebrate predation

While the direct effect of insect foliage predation on tree health is not very severe (Tanton, 1990), successive outbreaks of insects can eventually weaken or kill eucalypts by removing nutrients and water, and drying out foliage, resulting in defoliation (Ford, 1981; Morgan & Bungey, 1981; Tanton, 1990). The localised outbreaks of sap-sucking insects can occur as a result of increases in nitrogenous substances in foliage due to a deficiency of minerals and water (Ford, 1981). Reduced predation by birds may also lead to increased outbreaks of insects (Stone, 1999). Neyland (1996) found *E. viminalis* in the Tasmanian midlands had been most severely affected by tree health decline compared to other eucalypt species such as *E. amygdalina, E. ovata, E. tenuiramis,* and *E. dalrympleana*, which was probably the consequence of insect damage. There is a positive relationship between nitrogen content and the level of insect damage in the foliage of dieback trees (Landsberg & Wylie, 1983). *E. viminalis* has nutritious and palatable foliage resulting in it being targeted by a range of browsing animals and insects (Neyland, 1996).

Fire

Fire can cause both positive and negative effects on eucalypt health, and different consequences can develop depending upon the level of frequency and intensity of fire (Turner & Lambert, 2005). High fire frequency prevents the establishment of new tree seedlings and understorey shrubs, and prevents the accumulation of forest litter, which reduces extremes in soil temperature and helps retain surface soil moisture (Davidson, 2006). In contrast, a number of studies have reported the necessity of regular low-intensity fires to maintain eucalypt forest health and structure (Turner & Lambert, 2005). Regular low-intensity fires assist regeneration of eucalypts by providing minerals in the soil for germination, and light for growth of seedlings and lignotubers (Jurskis, 2005), as well as killing exotic understorey species. Therefore, the absence of fire for long periods may change understorey/overstorey interactions, and prevent adequate regeneration of eucalypt species (Davidson, 2006).

Grazing

Davidson *et al.* (2007) studied eucalypt decline in agricultural regions of the Tasmanian midlands, and concluded that grazing history (fencing, grazing frequency and intensity) was the primary threatening process in the context of three decades of below average rainfall in the region. While water stress may have increased the incidence of unhealthy trees, soil compaction as a result of stock grazing contributed to eucalypt decline due to the reduction in the ability of the roots to provide the plant with water and nutrients. Soil compaction also reduces soil water recharge due to reduction of water infiltration rates (Yates *et al.*, 2000).

Relationship between birds, insects and eucalypt dieback

Previous studies reported interactions between birds and insects as having a number of effects on eucalypt crown dieback (Ford, 1981; Loyn *et al.*, 1983; Lockwood & Gilroy, 2004; and Stone *et al.*, 2008). The abundance of birds in temperate woodlands in Australia has dramatically declined due to landscape change, habitat loss, fragmentation, and degradation (Ford *et al.*, 2001). The declining bird population negatively affects the woodland ecosystem, and one of the consequences is eucalypt dieback which commonly occurs in fragmented and degraded landscapes. Insectivorous birds play an important role in controlling populations of defoliating and sap-sucking insects. Declining abundance and diversity of these birds increases the insect population resulting in increased eucalypt dieback (Ford, 1981; Lockwood & Gilroy, 2004). The presence of aggressive birds defending relatively large territories, such as the *Manorina melanophrys* (bell miner) and *M. melanocephala* (noisy miner), can reduce the richness and abundance of smaller insectivorous birds (MacDonald & Kirkpatrick 2003, Lockwood & Gilroy, 2004). Because *M. melanophrys* does not always eat the psyllid nymphs (unlike pardalotes, which remove the psyllid together with lerps), insect numbers may increase (Loyn *et al.*, 1983).

3.1.2 Significance for *P. quadragintus* habitat assessment

Bryant (2010) reported that the Coffee Creek habitat appears to retain sufficient mature *E. viminalis* in good condition to support the previously estimated *P. quadragintus* population of 20 birds. However more recent estimates suggest that the population has declined to just 10 birds in the last 10 years. Until now a comprehensive tree condition survey has not been undertaken, and the reason for the declining bird population has not been examined in detail. Landsberg & Wylie (1983) reported that the level of insect damage tends to be higher on dieback trees due to the higher nitrogen foliage content in dieback trees. If this is the case, trees in poor condition may provide a higher amount of food for *P. quadragintus* due to the increase in lerps and manna. As the dieback progresses, crown thinning and significant dead branches develop, which leads to crown and tree death (Turner & Lambert, 2005) resulting in a loss of *P. quadragintus* foraging habitat. Other negative effect of dieback is exposing remnant to the wind and extreme temperatures, which is possibly making foraging more difficult and limited shelter opportunities resulting in leaving individuals and their nests more at risk from predation from aerial predators (Ford *et al.*, 2001). Besides, a lack of food can lead to increase in an interspecific competition. Ford & Paton (1982) reported that high levels of territoriality in honeyeater species are common in places where there are limited nectar resources.

If the *E. viminalis* in the Coffee Creek habitat are found to be of sufficient condition to provide foraging and breeding habitat for *P. quadragintus* then other factors must be considered to have negatively affected the bird density (e.g. human disturbance, isolation of the habitat, inter-specific competition, and direct destruction of breeding habitat and nesting trees) (Hinton *et al.*, 1981; Brown, 1986). An increase in aggressive bird species and a decrease in immigration of *P. quadragintus* from adjacent colonies can also be factors leading to a declining *P. quadragintus* population (Woinarski *et al.*, 1985). If this is the case, these factors may need to be identified and prioritised in the conservation management of the area in order to reduce the risk of the local extinction of *P. quadragintus*. Because no *E. viminalis* tree condition assessment, as part of a comprehensive *P. quadragintus* habitat assessment, has been undertaken, a tree condition assessment method needs to be developed. The simple tree condition assessment method enables researchers to conduct a tree condition survey on a regular basis and increases an understanding of the association between tree condition and *P. quadragintus*. This can be used to inform future reserve management and land use by prioritising actions in order to prevent the local extinction of *P. quadragintus*. A regularly undertaken tree condition survey can also provide a good opportunity to involve volunteer groups and/or local people and to increase their understanding of the species and its conservation.

It is not possible to examine the direct association between crown condition and bird population by comparing past tree condition with present data due to the absence of past data. As a result, this study examined tree condition at the Coffee Creek habitat and compared it to another previously known *P.*

quadragintus site known as the 'Township', on north Bruny Island. These two sites have the same history of population decline from 20 birds in 1997 to 10 birds in 2010 and contain a similar amount of remaining habitat. The results of the study confirm a relative level of tree condition at the Coffee Creek habitat, which can be used to identify the relationship between tree condition and *P. quadragintus* population for further study and examine potential causes of *P. quadragintus* decline. A tree condition survey and examination was also undertaken at each forest patch containing *E. viminalis* in Howden, as discussed in Chapter 2. The results of the survey will be used to compare with the locations of bird identification records and are discussed in Chapter 4. This may help to understand the quality of habitat required by *P. quadragintus* and make an estimation of suitable habitat size for *P. quadragintus* at Howden.

The main aim of this study is to produce a user-friendly tree condition assessment method to quantify *E. viminalis* tree condition. This tool can be used to assess the quality of *P. quadragintus* habitat for use in ongoing monitoring of *E. viminalis* tree health, and so help to predict *P. quadragintus* population trends. In addition this study examines the potential reasons for the declining *P. quadragintus* colony at Coffee Creek.

3.2 Methodology

3.2.1 Study site

The *Eucalyptus viminalis* quadrat crown condition survey was conducted on a private property called the 'Township' on north Bruny Island on 23rd and 24th of May 2010, and the habitat along Coffee Creek in the Peter Murrell Reserve and Conservation Area (Reserves) between 31st March and 5th May 2010. This survey was conducted for the purpose of making a comparison of habitat quality between the two sites which were previously known as habitat for a *P. quadragintus* colony. The Township site was selected because this habitat has some similarities with the Coffee Creek habitat. First, both locations have the same estimated population size of 10 birds in a similar habitat size - 12 ha in Coffee Creek (Bryant, 2010) and 16.5 ha in 'Township' (Brown, 1986). The size of Coffee Creek habitat may need to be modified due to the results of this study. Second, both sites contain small creeks with *E. viminalis* habitat occurring along these waterways. Third, it is estimated that the bird population in both areas has declined from 20 in 1997 to 10 in 2010 (Threatened Species Unit, 1998; Bryant, 2010). The one possible difference between two sites which may affect to *E. viminalis* crown condition is amount of rainfall. The Township site is located in more easterly site and may have received less rainfall than the Coffee Creek site. The site description of the Township site follows. (See Chapter 2 for a site description of the Coffee Creek habitat).

'Township' site

The study site Township (latitude 43° 05'S longitude 147° 21'E) is located approximately 3 km south of the township of Dennes Point at the northern end of Bruny Island (Figure 3-1). Bruny Island is the largest of Tasmanian's offshore islands and accommodates one of the two largest populations of *P. quadragintus*, along with the Maria Island population (Bryant, 2010). The study site Township is located between two other major *P. quadragintus* habitats which are Dennes Hill (40-50 birds) and Waterview Hill (20-30 birds) (Bryant, 2010). A relatively straight 4WD track runs up the middle of the habitat, adjacent to the creek from the Bruny Island main road and divides Dennes Hill and Waterview Hill.

The *P. quadragintus* habitat runs for approximately 0.5 km up either side of a gully. An olive orchard is located on the north-eastern boundary of the site and the land has been used for sheep grazing, especially the eastern slope of the gully which has been heavily grazed at the time Brown conducted the *P. quadragintus* survey in 1986. However, in recent years, sheep grazing has been occurred infrequently and irregularly only for reducing the fire hazard in the property. Evidence of a recent fire was reported by Brown (1986) when the site was inspected in May 1986, while the woodland on the northern upper slope had been burned in 1985. Since this time, the forest has regenerated with little evidence of major disturbance. The nearest weather station for recording temperature and rainfall is situated at Bull Bay (latitude 43° 09'S longitude 147° 36'E), approximately 1 km from the Township site. The mean maximum temperature for the area is 16.8 °C, and the mean minimum temperature is 8.8 °C. The mean total annual precipitation is 601.6 mm (Bureau of Meteorology, 2010d). The rock/soil type is dolerite on the eastern slope of the gully, and mudstone on the western slope, with evidence of contact metamorphism occurring in the form of hornfels at the base of the gully.

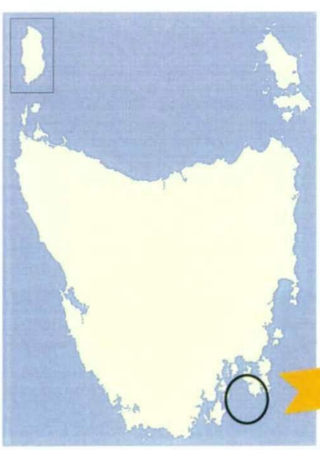


Figure 3-1 'Township' location map

3.2.2 Data collection

Quadrat setting

A total of 21 quadrats in the Coffee Creek site, including 17 quadrats in the Reserve and 4 quadrats outside the Reserve (Figure 3-2), were aligned at 50 to 100 m regular intervals from the northern end to Northwest Bay. In the Township site, 15 quadrats including 6 quadrats (T1, T2, T3, T4, T12 and T13) on the western slope (east facing aspect) and 9 quadrats (T5, T6, T7, T8, T9, T10, T11, T14 and T15) on the eastern slope (west facing aspect) were selected (Figure 3-3).The quadrat size were 20 m x 30 m for both sites. All quadrats were selected to include a higher number of *E. viminalis* trees (representative sampling method) rather than by random selection of quadrat site. Because of the purpose of this study, representative sampling method increases efficiency for assessing the tree condition of *E. viminalis* without seriously affecting the accuracy of the results. Individual *E. viminalis* of more than 15 cm in DBH were selected in each quadrat and the following recorded:

- tree growth stage (pole, mature, over mature, and dead)
- distance to the nearest *E. viminalis* (1 = <5 m; 2 = 5-10 m; 3 = 10-15 m; and 4 = >15 m),
- DBH (diameter at breast height),
- tree height,
- distance from water (1 = <5 m; 2 = 5-10 m; and 3 = >10 m),
- slope (1 = flat; 2 = gentle; 3 = moderate; 4 = steep), and
- *E. viminalis* crown conditions assessed from the ground using five crown condition parameters discussed below.

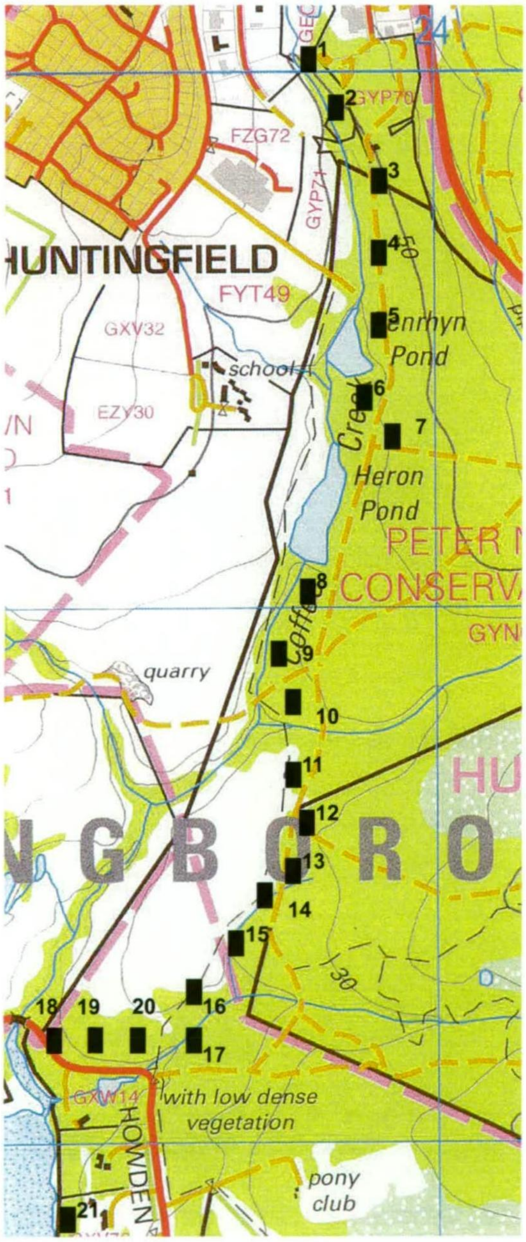


Figure 3-2 Quadrats at the Coffee Creek site

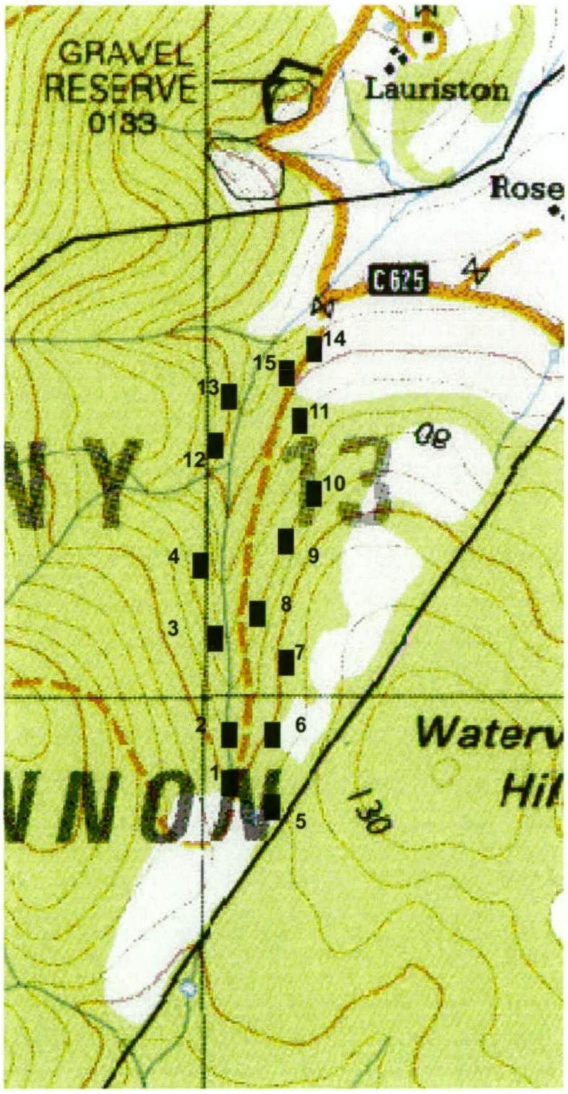


Figure 3-3 Quadrats at the 'Township' site

Crown condition assessment

Crown condition is frequently used as an indicator of tree decline and dieback and is considered a key attribute of forest health (Stone *et al.*, 2003; Horton *et al.*, 2010). Because of the food preference of *P. quadragintus,* i.e. lerps and manna (Woinarski *et al.*, 1985; Bulman *et al.*, 1986; Dorr, 1999), *E. viminalis* crown condition can be a key factor in assessing the habitat quality for *P. quadragintus*. The crown condition assessment methods were selected from Stone *et al.* (2003) and Wardlaw (1989), while some modification has been made for the purpose of this study. Definitions for each of the parameters are summarised in Table 3-1, and the crown condition assessment index is listed in Appendix 4.

Table 3-1 *E. viminalis* crown condition assessment parameters and score range

Parameter	Description	Score	References
Size	overall canopy size and shape	0-5	Stone *et al.* (2003)
Dead branches	dead branches	0-5	
Crown transparency	crown transparency	0-5	
Epicormic	crown epicormic growth	0-5	
Combined parameters	combination of the above four parameters (Size, Dead branched, Crown transparency and Epicormic)	0-20	
Dieback	proportion of the primary branches with dieback	0-5	Wardlaw (1989)

The five individual (not Combined) parameters were selected based upon a study by Horton *et al.* (2010), which examined some of the previous methodologies for the assessment of eucalypt dieback. Horton *et al.* (2010) concluded that the key attributes for accurate and precise assessment of crown condition in the field were combined single attribute methods developed by Stone *et al.* (2003) and Wardlaw (1989), especially the proportion of primary branches that have dieback. Wardlaw (1989) identified this as the key assessment parameter of crown condition, either as a percentage or as a scale. Combined scores of four parameters from the crown attributes of overall canopy size and shape, dead branches, epicormic growth and crown density from Stone *et al.* (2003), were found to contain the least amount of variation between observers, indicating that errors are not cumulative when scores are combined. This assessment method is suitable for less experienced observers due to the classification of each attribute from descriptions of the different levels (Horton *et al.*, 2010). One of the aims of this study is to develop an '*E. viminalis* Tree Condition Assessment Index' to allow researchers to conduct regular tree surveys to measure the *E. viminalis* condition trend in the medium to longer term. In addition, if it is possible for observers with relatively little experience to conduct a tree condition survey, the opportunity to collect sufficient data in a short time increases. Hence, the four assessment parameters (Size, Dead branched, Crown transparency and Epicormic) (Stone *et al.* 2003) were considered as a suitable method for this study and were utilised to assess *E. viminalis* crown condition, along with the proportion of primary branches that have dieback (Wardlaw, 1989).

Vegetation structure and environment survey

The vegetation structure and environment survey were conducted at each quadrat. Dominant plant species and the percentage cover in each vegetation layer were recorded by observation from the ground to the following classes: understorey = 0–1.5 m; midstorey = 1.5–10 m; and canopy = more than 10 m. The percentage cover of dominant surface type (e.g. leaf litter, bare soil, rock, vegetation and water surface) was also estimated. Other environmental variables noted included the evidence of fire, soil types, aspect, and weed species.

Climatic survey

Climatic data, such as rainfall and temperature, were acquired from the Australian Bureau of Meteorology website (http://www.bom.gov.au, 2010).

3.2.3 Data analysis

The size dimensions and crown condition parameters of *E. viminalis* are analysed between the Coffee Creek site and the 'Township' site by One-way ANOVA, and a level of $P < 0.05$ was taken to denote a significant relationship. Multivariate methods were used to explore the relationships between size dimensions of trees, tree growth stage, tree crown conditions, and location of trees.

Evidence of past fire (present or absent) and age structure (even-aged or uneven-aged) were recorded in each quadrat and used to define groups in a Multi-Response Permutation Procedure (MRPP) within PC-ORD, Version 4.27. A Euclidean (Pythagorean) distance measure was used to summarise differences between groups. The direction of strongest correlation for plant species and other environmental variables at a cutoff value of $R^2 = 0.3$ area were shown in vectors positioned across the ordination space.
Indicator values were calculated with the method provided by Dufrene & Legendre (1997).

3.3 Results

3.3.1 Relationship between crown condition parameters and size dimensions

The multivariate correlation analyses showed positive correlations between crown condition parameters (Table 3-2). The significant correlations were found between Combined parameters and all five single crown condition parameters (Size, Dead branches, Epicormic, Crown transparency, and Dieback). Size and Combined parameters showed the strongest correlation (r = 0.80) followed by Dieback and Combined parameters ($r = 0.77$).

Dieback also showed positive correlations with Dead branches, Size, and Crown transparency. Apart from the crown condition parameters, tree DBH and height showed a weaker correlation (r = 0.58). However, no correlation was found between size dimensions (either DBH or height) and any of crown condition parameters.

Table 3-2 Significant correlations among various measures of crown condition and tree size dimension

Variables		r
Combined parameters	Size	0.7992
Combined parameters	Dieback	0.7699
Combined parameters	Epicormic	0.7234
Combined parameters	Crown transparency	0.7143
Combined parameters	Dead branches	0.6945
Dieback	Dead branches	0.6412
Dieback	Size	0.6406
Height	DBH	0.5795
Crown transparency	Dieback	0.5625
Crown transparency	Size	0.5517

3.3.2 Comparison between Coffee Creek and Township habitat

Size dimensions of *E. viminalis*

A total of 186 *E. viminalis* trees at the Coffee Creek site and 128 trees at the 'Township' site were surveyed. The proportion of Class 1 (DBH 15-30 cm) trees was higher at 'Township' (31.3 %) compared to Coffee Creek (26.9%), while the proportion of Class 4 trees (DBH > 90 cm) was higher at Coffee Creek (12.9 %) compared to 'Township' (7.8 %) (Figure 3-4). This means the Township contained more regeneration compared to the Coffee Creek site but it had fewer large trees.

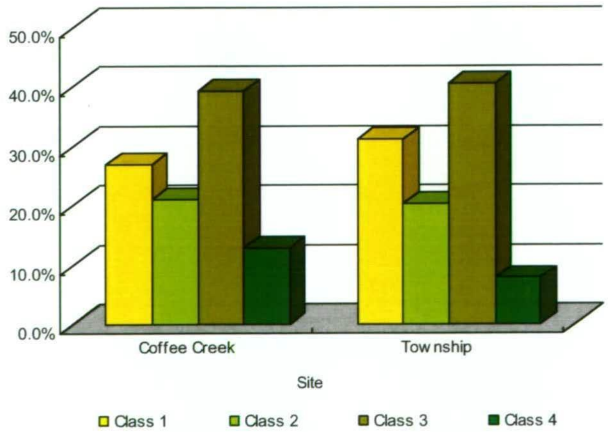


Figure 3-4 Proportion of each size class for *E. viminalis* trees surveyed at Coffee Creek and Township

Coffee Creek showed slightly higher mean DBH compared to the Township population, but the difference was not significant (ANOVA, $F_{1,312} = 2.7530$, $P = 0.0981$). Mean tree height was also higher at Coffee Creek which was slightly larger than for the Township population, but the difference was also not significant ($F_{1,312} = 3.1527$, $P = 0.0768$) (Figure 3-5 and Table 3-3). Mean DBH and height for *E. viminalis* at all quadrats were listed in Appendix 5.

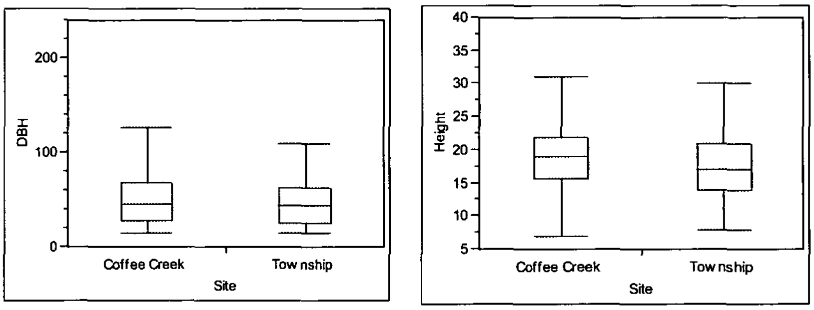


Figure 3-5 Box plot of the size dimensions of *E. viminalis* trees at Coffee Creek and Township (left) DBH, (right) height

Table 3-3 Mean size dimensions of *E. viminalis* trees at each location.
SE uses a pooled estimate of error variance

Location	n	DBH (cm) ± SE	Height (m) ± SE
Coffee Creek	186	55.68 ± 2.51	19.13 ± 0.41
Township	128	49.14 ± 3.03	18 ± 0.49

Canopy conditions of *E. viminalis*

Coffee Creek showed a significantly higher score for all of the parameters compared to the Township population. A strong significance was found in Size (ANOVA, $F_{1,310} = 91.2438$, $P < 0.0001$) and Dieback ($F_{1,310} = 77.6378$, $P < 0.0001$) (Figure 3-6 and Table 3-4).

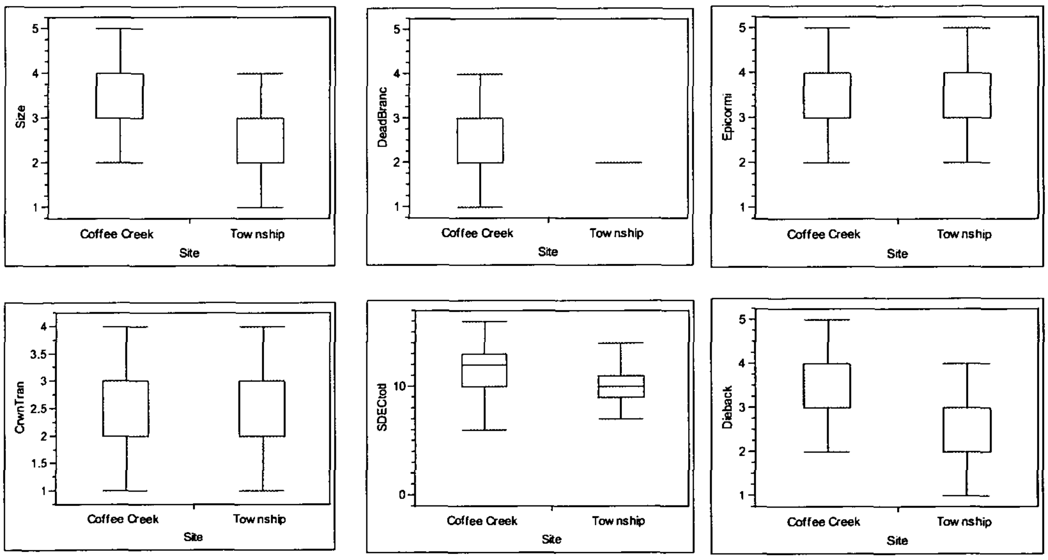


Figure 3-6 Box plot of *E. viminalis* crown condition parameters at Coffee Creek and Township top (left) canopy size and shape; (middle) dead branches; middle (right) epicormic growth; bottom (left) crown transparency; (middle) total score of 4 parameters; (right) dieback score of the primary branches.

Table 3-4 Mean crown condition score of *E. viminalis* trees at two sites
SE uses a pooled estimate of error variance

Site	n	Size ± SE	Dead branch ± SE	Epicormic ± SE	Crown transparency ± SE	4 total ± SE	Primary dieback ± SE
Coffee Creek	184	3.14 ± 0.06	2.29 ± 0.05	3.66 ± 0.07	2.53 ± 0.05	11.49 ± 0.17	3.67 ± 0.06
Township	128	2.29 ± 0.07	2.01 ± 0.06	3.34 ± 0.08	2.24 ± 0.06	9.88 ± 0.21	2.80 ± 0.08

Recruitment

While no significant difference in the number of seedlings and juveniles was identified between Coffee Creek and Township (ANOVA, $F_{1,34} = 1.9825$, $P = 0.1682$), Coffee Creek showed a higher mean number of seedlings and juveniles with 7.14 ± 2.96 compared to Township with 0.66 ± 3.51. In Coffee Creek an extremely high number of seedlings and juveniles (83) were found in C1. No seedlings and juveniles were found at six quadrats (29 %) at Coffee Creek and eight quadrats (53 %) at Township. In Township, seven quadrats located on the eastern side of the gully (from T5 to T11) had a total of only 2 seedlings and juveniles (20 %) (Table 3-5).

Table 3-5 Number of seedlings and juveniles at Coffee Creek and Township

	n	Mean ±SE	Frequency	
Coffee Creek	21	7.14 ± 2.96	15	71.4%
Township	15	0.66 ± 3.51	7	46.7%

Dominant plant species

Coffee Creek showed a significantly higher mean coverage of *E. viminalis* (61.0 %) than other canopy tree species, such as *E. obliqua* (16.3 %) and *E. ovata* (10.0 %). While *E. viminalis* also showed the highest mean coverage at Township with 31 %, the differences of the mean coverage with other canopy tree species, such as *E. obliqua* (20.0 %), *E. pulchella* (18.3%) and *E. globulus* (14.2 %) were not as significant as at Coffee Creek. *E. viminalis* (18.3 %) also showed the highest mean coverage in the middle storey at Coffee Creek, while no *E. viminalis* was recorded in the middle storey at Township. Two shrubs, *Bursaria spinosa* (13.9 %) and *Acacia verticillata* (12.0 %), were the dominant middle storey species at Township, while they were not recorded at Coffee Creek. *Pteridium esculentum* (81.2 %) showed significantly high mean coverage at Coffee Creek, but had a very low mean coverage at Township with only 4%. In contrast, two native grass species, *Poa* spp. (47.9 %) and *Themeda triandra* (40.0 %), showed the highest mean coverage at Township. Mean coverage of leaf litter was much higher at Coffee Creek (92.1 %) than Township with (66.3 %) (Table 3-6).

Table 3-6 Dominant plant species in each vegetation layer at Coffee Creek and Township. Figures in bold represent the highest percentage within each layer

	Coffee Creek		Township	
	Mean (%)	Frequency rate (%)	Mean (%)	Frequency rate (%)
Canopy				
E. amygdalina	9.5	47.6	-	0.0
E. globulus	-	0.0	14.2	40.0
E. obliqua	16.3	19.0	20.0	33.3
E. ovata	10.0	9.5	-	0.0
E. pluchella	-	0.0	18.3	46.7
E. tenuiramis	-	0.0	4.0	13.3
E. vimimalis	**61.0**	100.0	**31.0**	100.0
Middle sotrey				
Acacia melanoxylon	12.9	85.7	7.8	33.3
A. verticillata	-	0.0	12.0	80.0
Bursaria spinosa	-	0.0	**13.9**	86.7
E. viminalis	**18.3**	14.3	-	0.0
Melaleuca squarrosa	12.8	42.9	-	0.0
Understorey				
Leptospermum scoparium	15.0	14.3	14.3	20.0
Melaleuca squarrosa	20.0	4.8	-	0.0
Poa spp.	-	0.0	**47.9**	93.3
Themeda triandra	-	0.0	40.0	46.7
Pteridium esculentum	**81.2**	100	4	40
Ground cover				
Leaf	**92.1**	100.0	**66.3**	100.0
Vegetatiion	**16.8**	28.6	**60.3**	100.0
Baresoil	4.2	42.9	7.6	33.3

Ordination of the quadrats

A NMDS ordination of the quadrats containing *E. viminalis*, based upon vegetation community and ground cover, completely separated Coffee Creek and Township localities (Figure 3-7). However, the Coffee Creek quadrats were more tightly clustered in the top left of the ordination space than the Township quadrats which were widely dispersed in the bottom half of the space. Variables most strongly associated with the Coffee Creek quadrats were cover of *Pteridium esculentum* in the understorey, *E. viminalis* in the overstorey and leaf litter. Variables associated with Township were related to grassy woodland species such as *Themeda triandra* and *Poa* spp. in the understorey and shrubs such as *Acacia verticillata* and *Bursaria spinosa.*

The evidence of fire was found in all quadrats at Township and in 10 of 21 quadrats at Coffee Creek. A significant difference in community composition was shown between quadrats grouped by past fire evidence and non fire evidence ($P < 0.01$) (Figure 3-7, Table 3-7 and Appendix 6).

Substrate variables were different at the site level, with dolerite and mudstone underlying all the Township quadrats and sandstone associated with all the Coffee Creek quadrats (Figure 3-7 and Appendix 6).

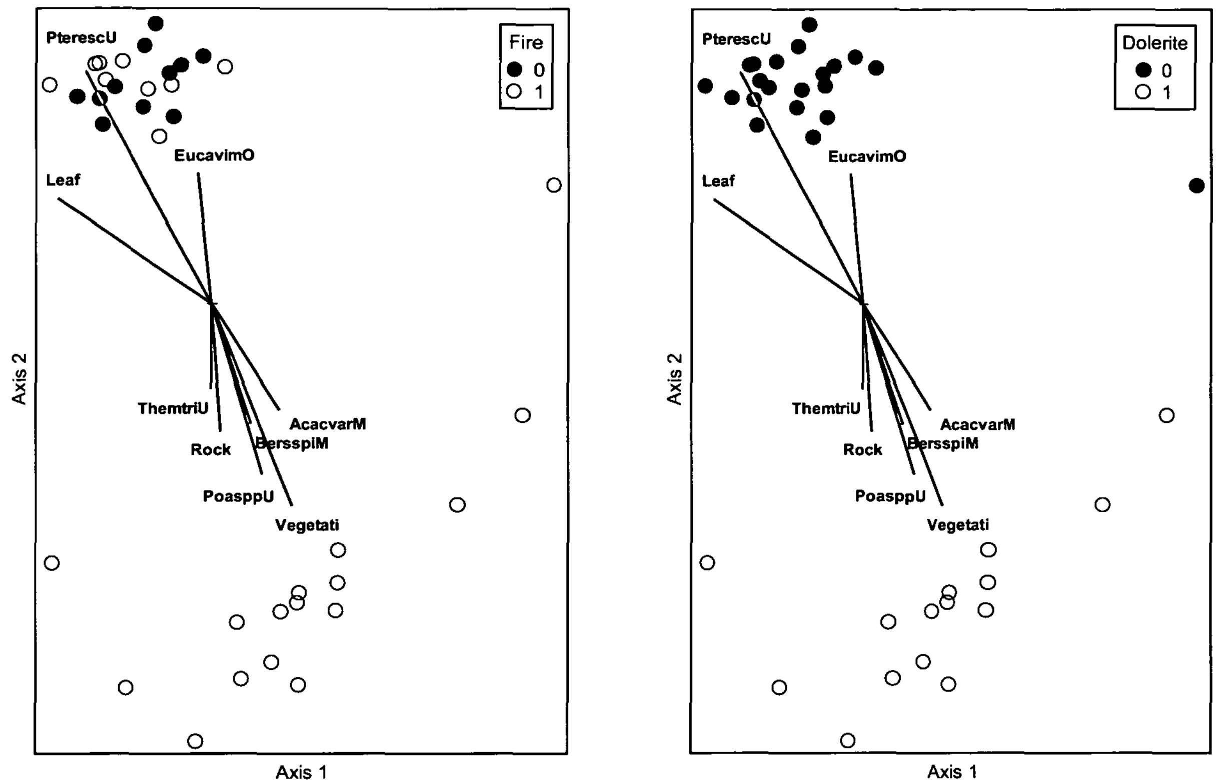


Figure 3-7 Ordination (NMDS) of quadrats at Coffee Creek and Township containing *Eucalyptus viminalis*, based upon vegetation community attributes. Stress in 2 dimensions = 8.598%, cutoff R^2=0.300.
(left) presence of fire evidence 0 = past fire evidence present, 1 = past fire evidence absent; (right) Type of substrata 0 = sandstone 1= dolerite and mudstone

Table 3-7 Results of the MRPP test for differences between quadrats grouped by past fire evidence

	n	Average distance	Obs delta	A	p
Fire present	25	1.0704	-	-	-
Fire absent	11	0.5601	0.9145	0.1046	0.0003

Climatic analysis

Annual rainfall for the last 15 years at Taroona, which is the nearest weather station for rainfall to Coffee Creek, and at Bull Bay, which is the nearest weather station to Township, showed very similar trends. Taroona showed a slightly higher mean annual rainfall of 621 mm compared to Bull Bay with 607 mm. Both sites had very low annual rainfall for the previous three years between 2006 and 2008, especially in 2006 when rainfall was extremely low with 339 mm (55 % of mean annual rainfall) at Taroona and 336 mm (62 % of mean annual rainfall) at Bull Bay (Figure 3-8).

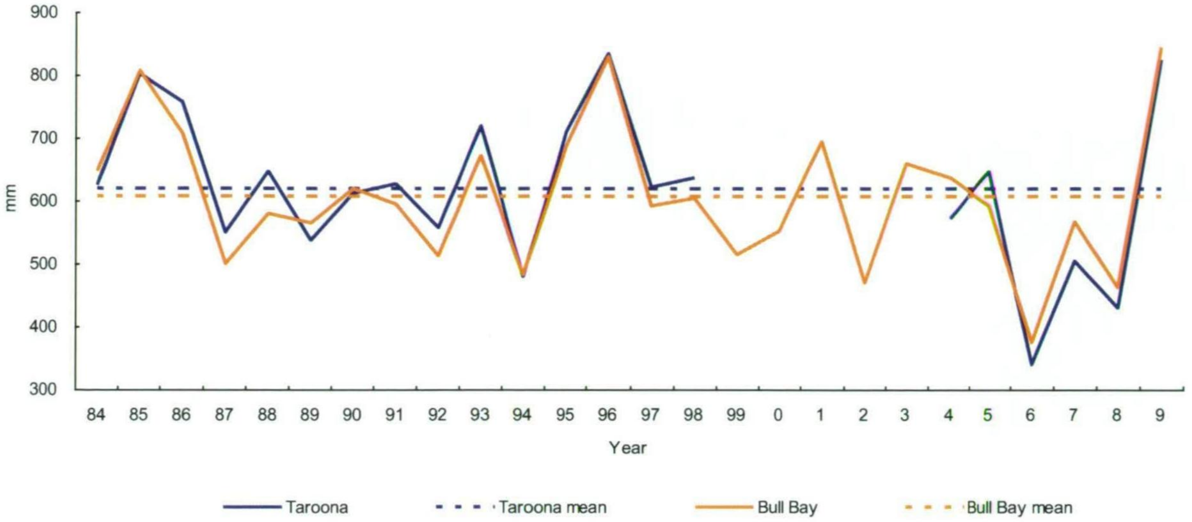


Figure 3-8. Annual rainfall (mm) between 1984 and 2009
Taroona (blue line) and Bull Bay (orange line) Data between 1999 and 2003 in Taroona was missing (Bureau of Meteorology, 2010c & 2010d).

3.5 Discussion

3.4.1 Crown condition parameters for *P. quadragintus* habitat assessment

The results of this study showed a positive relationship between the proportion of primary branches that have dieback (Dieback) and Combined parameters (Size, Dead branches, Epicormic growth, and Crown transparency). This result indicated that only one of these attributes, Combined parameters or Dieback, can be used for crown condition assessment. Horton *et al.* (2010) suggested both Dieback and Combined parameters as key attributes for crown condition assessment in the field, and concluded that Dieback is more accurate and precise than Combined parameters. However, I would argue that Combined parameters is more suitable for the Crown Condition Assessment Index as a part of *P. quadragintus* habitat assessment, compared to Dieback. This is because the combined score of Combined parameters does not accumulate errors associated with field survey (Horton *et al.* 2010). The Crown Condition Assessment Index can be used for a continuous monitoring program of the *P. quadragintus* habitat when observers are likely to be people with non-professional experience of tree condition assessment.

No correlations between Epicormic growth and any other parameters were identified in my study. This was in contrast to Horton *et al.* (2010), who found a significant positive correlation among all crown condition parameters, including Epicormic growth. The assessment of epicormic growth can be relatively difficult to score due to the difficulty in differentiating between primary and epicormic growth. As a result, epicormic foliage had the lowest repeatability of any variable in their study (Horton *et al.*, 2010). Inaccurate observations for the crown condition survey in this study could be one reason for the different result in the relationship between epicormic growth and other parameters. It is also difficult to confirm whether epicormic growth represents continuing decline or recovery from stress such as growth suppression, fire or drought (Ellis *et al.* 1980; Podger *et al.* 1980).

Consequently, Size, Dead branches, and Crown transparency, were considered to be suitable attributes for the Crown Condition Assessment Index for *P. quadragintus* habitat assessment, as they are simpler and when repeatedly surveyed will minimize errors made by less experienced observers. The Crown Condition Assessment Index is included in the sample of the *P. quadragintus* habitat assessment attached in Appendix 4. While eucalypt species are categorised as evergreen trees, nevertheless, the crown foliage density is influenced by seasonality, with growth and leaf senescence peaking in summer for temperate eucalypt species (N. Davidson, personal communication, 2010). Hence, the *E. viminalis* crown condition survey needs to be conducted in the same season for accurate monitoring of trends in the crown condition.

The results of this study showed no correlation between size dimensions (either DBH or height), and any of the crown condition parameters. This indicated that the dieback and decline is not necessary confined to large older trees (Kirkpatrick *et al.*, 2000). In other words, factors other than age, affect *E. viminalis* crown condition.

3.4.2 Habitat attributes at Coffee Creek and Township

Suitability for breeding habitat

The result of this study showed the Coffee Creek site includes a higher proportion of *E. viminalis* Class 4 trees (DBH > 90 cm) than the Township site. Class 4 trees are recognised as large trees potentially providing nesting sites for *P. quadragintus* (Bryant, 2010). However, a number of large, dying and dead *E. obliqua, E. globulus* and *E. tenuiramis* were observed at Township. These also provide hollows in fallen limbs and dead logs on the ground which *P. quadragintus* can use as nesting sites. Woinarski & Bulman (1985) reported more than half of the nesting sites that they found were stumps, fallen trees or limbs, and occasionally holes in the ground. Hence, stumps, fallen limbs, dead logs on the ground and large non-*E. viminalis* trees need to be included in *P. quadragintus* habitat assessment as well as the proportion of *E. viminalis* Class 4 trees.

Potential cause of *E. viminalis* decline

The result of the crown condition analysis identified that the Coffee Creek habitat contains *E. viminalis* trees with better crown conditions than the Township habitat. This result was consistent with the result of Bryant (2010), which surveyed a canopy projective cover as one of the parameters to assess the *P. quadragintus* habitat quality, and found that *E. viminalis* decline on Bruny Island was higher than that in the Coffee Creek area. The summary of the site attributes based upon the survey results are listed in Table 3-8. The possible cause of the *E. viminalis* decline in the Township habitat and the reasons for the difference of crown condition between the two sites were examined.

The last 15 years rainfall history, including three continuous years (between 2006 and 2008) of below average rainfall, showed almost the same amount and trends between the two sites. This suggests that the rainfall quantum in the recent past did not differentially affect *E. viminalis* decline in the Township habitat, which supports some previous studies suggesting that drought was not the primary cause of eucalypt dieback. However, a study conducted in Tasmania found eucalypt decline to be severe where the annual average rainfall is below 625 mm per annum (Grice, 1995), which is the case for both sites in this study. In addition, there are some environmental and land management factors that contribute to the level of water availability to plant species, such as soil/rock types, topography and grazing history.

Table 3-8 Summary of site attributes

Parameter	Coffee Creek	Township
Estimated bird population size	20 (1997) -10 (2010)	
Estimated habitat size	29 ha*	16 ha
Nearest *P. quadragintus* colony	Tinderbox (Approx. 5 km away)	Dennes Hill (contiguous)
Main vegetation community type	*E. amygdalina – E. viminalis – E. obliqua* forest with shrub understorey	*E. pulchella – E. globulus – E. viminalis* grassy shrubby dry sclerophyll forest
E. viminalis canopy cover	61 %	31 %
Class 4 trees (DBH > 90cm)	12.9%	7.8%
Combined parameters crown condition	11.49 ± 0.17	9.88 ± 0.21
E. viminalis recruitment	7.14 ± 2.96	0.66 ± 3.51
Rock type	Sandstone	Dolerite and mudstone
Grazing	No	Yes
Recreational use	Suspected high	Suspected low
Fire evidence	Present at half number of the quadrats	Present at all quadrats
Level of Isolation of the forest/woodland	Higher	Low
Annual rainfall for last 15 years	Under 625 mm per annum (average for last 15 years)	

* Habitat size in the Coffee Creek site was estimated in Chapter 4 through this study.

Kirkpatrick (1981) reported that topography, combined with soil type, determines the moisture availability to plant species. The soil type in the Coffee Creek habitat is derived from Quaternary sands and in Township is derived from mudstone and dolerite parent materials. The water-holding capacity is higher in sandstone than mudstone soils, which in turn is higher than dolerite soils (Kirkpatrick *et al.*, 2000). This might indicate that the Coffee Creek habitat has higher water availability to plant species than the Township site despite the amount of rainfall at both sites being the same. A notable difference in topography was apparent between the two sites. Township habitat is located on moderate to steep slopes, while the Coffee Creek habitat is located in a relatively flat area with several small tributaries flowing into Coffee Creek. The water-holding capacity and drainage patterns of an area influence both the middle storey and understory plant species. In the Coffee Creek habitat *Melaleuca squarrosa* occurs in both middle storey and understorey, while no *M. squarrosa* was identified in the Township habitat. In contrast, in the Township *Bursaria spinosa* and *Acacia verticillata* are the main middle storey plant species, while these two species did not occur in the immediate Coffee Creek habitat. *M. squarrosa* forms extensive colonies in wetter areas (Whiting *et al.*, 2004), while *A. verticillata* mostly occur in a dryer habitat. There is a stock grazing history in the Township, but not in the Coffee Creek habitat. Grazing can be a factor in the water-holding capacity of an area. With a habitat that has been grazed there may reduce water infiltration rates due to soil compaction resulting in reduction of soil water recharge (Yates *et al.*, 2000). Another factor that might result in difference in water availability between the two sites is the presence of additional water sources. The Coffee Creek habitat receives large amounts of runoff water from the adjacent golf course and three reservoirs (Penrhyn pond, Heron pond and an unnamed pond) along Coffee Creek, whereas the Township site is drier with less runoff water and contains only two small dams in the gully.

All of the above factors suggest that the Coffee Creek site has a higher water availability to plant species compared to the Township site. It could be that due to the poorer water-holding capacity of the Township site, the effect of low rainfall is more pronounced resulting in increased crown dieback.

The result of *E. viminalis* recruitment showed that the Coffee Creek habitat had a higher mean number and frequency of seedlings and juveniles when compared to Township, especially on the eastern side of the gully, where the influence of grazing might be a significant reason for an extremely low rate of seedlings and juveniles. The ability of seed germination is affected by moisture availability as well as temperature, because seeds must achieve relative water contents sufficient for germination processes to occur (Yates *et al.*, 1996). These results suggest that grazing combined with low water availability has brought about a reduction in *E. viminalis* recruitment.

Relationship between crown condition and the *P. quadragintus* population

The crown condition at both the Coffee Creek and the Township sites were examined and combined with the environmental factors in relation to the *P. quadragintus* population. The previous study reported that the level of insect damage tends to be higher on dieback trees (Landsberg & Wylie, 1983), which may imply an increased food source for *P. quadragintus*. However, *E. viminalis* crown condition was poor in the Township habitat where *P. quadragintus* population has declined from 20 to 10 in the last 10 years (Bryant, 2010). This result may indicate that the declining *E. viminalis* crown condition has negatively affected the sustainability of the bird population. This might be because the dieback has progressed to such as extent that the remaining foliage is not healthy enough to support a *P. quadragintus* population of 20 or more birds. Scarcity of food can increase interspecific competition, which can reduce the availability of suitable nesting sites, increase the limitation of food resources, and waste of time through interspecific interactions (Woinarski & Bulman, 1985). These can be causes of nesting failure (Woinarski & Bulman, 1985), which will in turn reduce the bird population. Reduced and scattered foliage in a tree crown can also result in a lack of cover from predators. In contrast, the Coffee Creek habitat sustains *E. viminalis* with relatively good crown condition, but the bird population has also declined from 20 to 10. This result seems to suggest that the decline of the *P. quadragintus* population at Coffee Creek was not linked with crown condition of *E. viminalis,* and other factors are likely to have contributed. Potential causal factors for this decline at Coffee Creek are: 1) increase in adjacent residential development in the surrounding environment resulting in isolation of the habitat and elevated levels of human disturbance; 2) increase in human recreational activities which has higher impacts on and is adjacent to the Coffee Creek habitat; 3) increase in edge effects resulting in a higher number of aggressive birds and predators; and 4) increase in inter-specific competition. These potential causes are discussed further in Chapter 4 and 5.

It was not possible in this study to confirm a causal conclusive relationship between crown condition decline and the declining *P. quadragintus* population. Additional surveys would be required in order to further elaborate the nature of this relationship. An additional survey of *E. viminalis* crown condition in a habitat with no population decline (such as a third site e.g. INALA on Bruny Island between 1997 and 2010) could be conducted to increase an understanding of the relationship between crown condition and sustainability of a *P. quadragintus* population.

Chapter 4: Habitat preference of *P. quadragintus*

P. quadragintus Photo by Graeme Chapman

4.5 Introduction

4.1.1 Habitat selection of birds

A number of habitat quality characteristics such as habitat area size, vegetation type and vegetation structure, have an influence on the habitat selection of birds. The different effects of these habitat characteristics produce variation in habitat use as different bird species prefer/tolerate different combinations of attributes, such as food type, nesting sites, and degree of susceptibility to competitors and human disturbance (Mörtberg, 2001; Kark *et al.*, 2007). Cody (1981) discussed three factors – vegetation structure, competition and habitat productivity – as constraints on habitat acceptability to birds. He argued that these factors must be considered jointly when undertaking accurate predictions of a bird species preferred habitat. For instance, the structure and density of vegetation are important habitat characteristics for insectivorous birds because these features affect the abundance of arthropods (Cody, 1981). Vegetation structure and density also influences the availability of favoured nesting sites and shelters to hide from predators (Cody, 1981). Montague-Drake *et al.* (2009) reported that in thickly-vegetated areas are critical in providing shelter and nest sites for thirteen different bird species surveyed. Interspecific competition can also be increased if the abundance of food is low (Ford, 1985).

Although food availability and density is known to have an affect on the presence or density of insectivorous birds, it is difficult to confirm the productivity of the habitat and the relationship with the habitat selection of individual bird species (Cody, 1981). One of the reasons making it difficult to identify associations between insectivorous birds and habitat productivity is that the abundance of food changes depending upon seasons and even diurnally (Timewell & MacNally, 2004). For instance, birds that depend upon energy rich carbohydrates, such as lerps and manna, select plant species as foraging substrates on the basis of the abundance of a particular arthropod. However, during winter and autumn insect abundance and activity is low and birds need to change their foraging habitat and use alternative food sources (Recher, 1996; Dorr, 1999). To avoid increased competition due to low abundance of food, some bird species migrate or disperse locally to seek areas of higher food abundance (Ford, 1985). In addition to the broader food requirements of birds, over shorter periods, such as during a breeding season, some species rely on finding different types of nutrition to feed juveniles depending upon their growth stage. Oliver (1998) studied the food for juveniles of *Xanthomyza phrygia* (regent honeyeater) and found that nestlings were fed insects more often than were fledglings due to their requirement for higher protein intake for rapid growth.

In the sub-urban landscape, remnant forest/woodland size and pressure from human disturbance affects the habitat selection of birds. A number of studies have been conducted that investigate habitat requirements in fragmented landscapes, especially for woodland bird species of conservation concern (Lloyd, 2008; Montague-Drake *et al.*, 2009). These studies found that increased pressures, such as habitat fragmentation in the surrounding landscape, leads to a decline in many woodland bird species. An additional finding was that larger patches support more favourable habitat due to less area influenced by edge effects (Lloyd, 2008; Montague-Drake *et al.*, 2009). A definition and negative impacts of edge effects on bird species is discussed in Chapter 5. Montague-Drake *et al.* (2009) found eight of thirteen woodland bird species, such as *Microeca fascinans* (jacky winter), *Myiagra inquieta* (restless flycatcher) and *Climacteris picumnus* (brown treecreeper), were more likely to occupy larger patches in agricultural area in New South Wales. Hence, many variables other than availability of feeding substrates, such as landscape and habitat attributes, including interactions between patch condition and characteristics of the surrounding landscape, can influence the presence of species (Montague-Drake *et al.*, 2009).

4.1.2 Significance of the identification of habitat quality for *P. quadragintus*

Previous studies have identified the habitat preference of *P. quadragintus* for *E. viminalis,* and that a suitable habitat needs to include an *E. viminalis* canopy cover of 10 % or more (Woinarski & Bulman, 1985; Brereton *et al.*, 1997; Dorr, 1999). Also, a correlation between the amount of *E. viminalis* and the abundance of *P. quadragintus* has been documented by Woinarski & Rounsevell (1983) and Woinarski & Bluman (1985). *P. quadragintus* also favours large *E. viminalis* trees within a habitat, a preference that Bryant (2010) suggests stems from their ability to provide suitable nesting sites for the bird. A number of other habitat qualities and characteristics of the surrounding landscape probably influence *P. quadragintus* when selecting their foraging and breeding habitats. These include food availability in relation to vegetation structure, *E. viminalis* tree size and tree health, and human related disturbance pressures (e.g. consistent noise, human activities, habitat fragmentation) from the surrounding landscape. However, these characteristics have not been examined in previous studies. Understanding the key characteristics of habitat quality is critical for designing habitat management strategies for bird species of conservation concern, such as *P. quadragintus,* to secure viable endangered species populations (Cameron & Cunningham, 2006; Lloyd, 2008).

The main aim of this chapter is to identify the habitat preferences of *P. quadragintus*. This is achieved by examining the habitat attribute variables in forest patches containing *E. viminalis* and comparing these variables with the number of times birds were detected in these areas. This information will extend our understanding of the importance of habitat quality for *P. quadragintus* and predict the type of forest patches preferred and used by the bird for foraging and breeding habitat. The effects of the pressures from surrounding landscapes on *P. quadragintus* habitat are examined in Chapter 5. The results of this enquiry can also be used to make an estimation of the total habitat extent available to the *P. quadragintus* population at Howden.

4.2 Methodology

4.2.1 Study area

The study area is the Peter Murrell Reserve and Conservation Area and its immediate surrounds. A description of this area is previously presented in Chapter 2. A total of 32 forest patches containing *E. viminalis* were identified (Figure 2-7) and these were separated into 3 groups; Coffee Creek (24 patches), Mid-eastern (3 patches) and Channel Highway (5 patches) based upon their location in the landscape (Figure 2-6). In this Chapter, *P. quadragintus* detection rate in relation to the habitat attributes was surveyed and analysed based upon these individual patches and patch groups.

4.2.2 *E. viminalis* tree dimensions and crown condition survey

An *E. viminalis* crown condition survey was conducted between 31st March and 30th June 2010 in each forest patch containing *E. viminalis*. *E. viminalis* trees with a DBH which exceeded 15cm were randomly selected and DBH, height, and crown condition were recorded. All Class 4 trees (DBH > 90cm) within the patches were selected for size measurement and crown condition assessment. In terms of crown condition assessment, five single parameters (Crown size, Dead branches, Epicormic growth, Crown transparency, and Dieback) were selected. The reason for the selection of these parameters and the summary of each parameter is described in the methodology section of Chapter 3. Other patch attribute variables, such as canopy coverage of eucalypt species, dominant plant species, number of class 4 trees, have been surveyed and analysed in Chapter 2.

4.2.3 Foliage survey

A foliage condition survey was conducted on 29th August, 6th, 8th and 11th September 2010, after a few days of strong winds which resulted in opportunities to collect fresh green leaves that had been stripped from the canopy and deposited on the ground. More than 50 fresh *E. viminalis* leaves were collected randomly from each of the 32 patches. These are argued to represent a random, or at least a haphazard, sample of the canopy foliage. If 50 fresh leaves could not be found in a patch, as many as possible were collected. Individual leaves were assessed and recorded for different types of insect damage, such as galls, leaf mines, lerps, chewing on edge, and chewing in interior. Leaf area loss was estimated for each leaf according to six percentage classes: 1 = >1 %; 2 = 1-5 %; 3 = 5-10 %; 4 = 10-20 %; 5 = 20-50 %; and 6 = > 50 %. An index of leaf area loss and type of leaf damage is shown in Appendix 7.

4.2.4 *P. quadragintus* survey

A *P. quadragintus* survey was conducted on 2nd September 2010 by 3 people (S. Bryant, D. Abbott and C. Iijima) and on 8th September 2010 by 2 people (S. Bryant and C. Iijima). Two census methods, area searching and transects, were used for previous *P. quadragintus* population surveys by Brown (1986, 1989) and Bryant (1997, 2010). The area searching method was used for colonies of less than 3 to 5 ha in size and involved searching all *E. viminalis* trees, walking slowly throughout the entire colony listening for calls and actively scanning all *E. viminalis* canopies for any sign of pardalote movement. If movement was detected then the species was positively identified using binoculars. The transect method was used for colonies greater than 3 to 5 ha in size and involved walking slowly on a path throughout the colony while actively searching *E. viminalis* canopies up to 50 m either side. If required, stopping and searching was undertaken at least 100 m apart between the stop points to avoid double counting (Bryant, 2010).

The purpose of this study was to identify habitat quality for *P. quadragintus* by examining the relationship between bird detection and habitat attributes. Therefore the presence or absence of *P. quadragintus* needed to be surveyed at each patch by using both the area searching and transect methods (a map of forest patch containing *E. viminalis* is provided in Chapter 2, Figure 2-7). Whenever *P. quadragintus* was detected, their position was recorded using a GPS receiver. The transect survey involved walking on tracks and roads and stopping at several points for 20 minutes to actively search *E. viminalis* canopies within a 50 m radius. The stopping points were at intervals of at least 100 m and were selected to enable searchers to cover most of the

E. viminalis patch areas. In addition, *P. quadragintus* identification was recorded during all visits to *E. viminalis* patches throughout the entire study period (between 3rd February and 8th September 2010).

4.2.5 Data analysis

The size dimensions and crown condition parameters of *E. viminalis* were analysed by One-way ANOVA for the three patch groups (Coffee Creek, Mid-eastern, and Channel Highway) and all individual patches, with a level of $P < 0.05$ taken to denote a significant relationship. Crown condition was assessed by combining 3 separate parameters: Crown size, Dead branches, and Crown transparency, because the results of the examination of crown condition survey suggested that using 3 parameters in combination (Crown size, Dead branches, and Crown transparency) minimises the error in crown condition assessment (Chapter 3). Multivariate methods were used to explore the relationships between the size dimensions of trees, tree crown conditions, and leaf damage caused by insects.

Detection data of *P. quadragintus* from a previous population survey (conducted between December 2009 and February 2010) by Bryant (2010) was used to produce a location map and analysis of habitat quality for *P. quadragintus*. The use of multiple data sources was necessary because sufficient data for analysis could not be collected during this short study period. No significant environmental stochastic event occurred in the previous 12 months and the landscape, including bird habitat, was not subject to dramatic change over this period. In addition, aspects of habitat quality such as leaf damage and crown condition were considered not to have changed rapidly. Consequently, Bryant's bird detection data was supplemented with data collected throughout my entire study period between February 2010 and September 2010. The *P. quadragintus* detection data was analysed in relation to the forest patches containing *E. viminalis*. The likelihood of detection of *P. quadragintus* was calculated according to the number of visits. A visit was defined as a researcher(s) spending more than 10 minutes in or around patches searching a 50 m radius for the presence of *P. quadragintus*.

Attribute variables of forest patches containing *E. viminalis* were used to identify the likelihood of bird detection at each patch in a Multi-Response Permutation Procedure (MRPP) within PC-ORD, Version 4.27. A Euclidean (Pythagorean) distance measure was used to summarise differences between patches. The direction of strongest correlation for variables at a cutoff value of $R^2 = 0.200$ were displayed as vectors positioned across the ordination space.

The relationship between the *P. quadragintus* detection rate and a total of 14 environmental attribute variables, including *E. viminalis* tree size, leaf damage, and crown condition and geographical information, were examined using a Principal Components Analysis (PCA).

A Logistic Regression and a Stepwise Regression model were tested to further identify the relationship between occurrence (presence/absence) of *P. quadragintus* and a cross section of the measured environmental variables to propose a model for prediction of the detection rate of *P. quadragintus*.

4.3 Results

4.3.1 *E. viminalis* size dimensions and tree condition at Howden

Size dimensions

E. viminalis mean DBH showed significant difference among the three groups (ANOVA, $F_{2,880}$=56.0503, P < 0.0001). The highest DBH (mean ± SE) was found at the Channel Highway group (65.2 ± 2.85 cm) and the lowest mean DBH was found at the Mid-eastern group (28.5 ± 2.55 cm) (Figure 4-1). The mean DBH also differed significantly between individual patches (ANOVA, $F_{31,962}$ = 15.9531, P < 0.0001). The patches containing highest and lowest mean DBH were found in the Coffee Creek group - patch number 1 (116.30 ± 12.46 cm) as the highest and patch number 9 (18.49 ± 5.77 cm) as the lowest (Figure 4-2). All three patches of the Mid-eastern group had a very low range of mean DBH and were in the patches of five lowest mean DBH. The patches in the Channel Highway group were distributed in the middle DBH class (Figure 4-2).

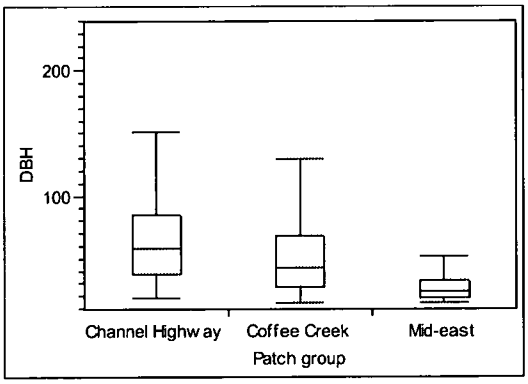


Figure 4-1 Mean DBH (cm) in the three patch groups

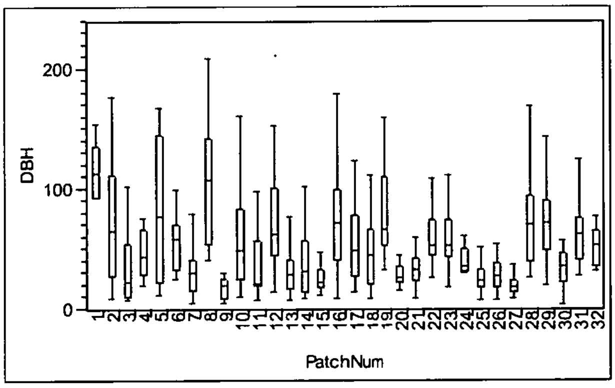


Figure 4-2 Mean DBH (cm) at each forest patch
Coffee Creek: patch number 1 to 24, Mid-eastern: 25-27, and Channel Highway: 28-32.

Patches 9 and 27 had the highest proportion of Class 1 trees (DBH = 15-30 cm) with no Class 4 trees (DBH > 90 cm), and the lowest proportion of Class 3 trees (DBH = 45-90 cm). Other patches with no Class 4 trees were patches 7, 15, 20, 21, 24, 25 and 26 (Figure 4-3). In contrast, patches 1, 8, 12, 19, 24, and 32 had no record of Class 1 trees. Patch number 1 consisted of only Class 4 trees.

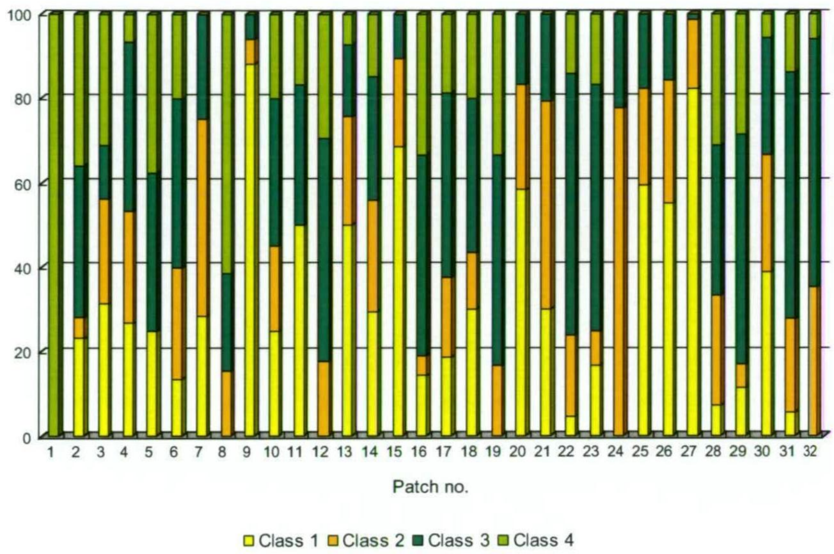


Figure 4-3 Proportion (%) of DBH class in each forest patch
Class 1 = DBH 15-30cm; Class 2 = DBH 30-45cm; Class 3 = DBH 45-90cm; and Class 4 = DBH >90cm

Mean height showed significant difference among the three groups (ANOVA, $F_{2,876}$=90.2264, P < 0.0001). The highest mean height was found in the Channel Highway group (21.27 ± 0.422 m) and the lowest mean height was found in the Mid-eastern group (18.03 ± 0.22 m) (Figure 4-4). The mean height also differed significantly between individual patches (ANOVA, $F_{31,958}$ = 22.6031, P < 0.0001). Patches containing the highest mean height and the lowest mean height were found in the Coffee Creek group - patch number 1 (27.17 ± 1.89 m) as the highest and patch number 9 (10.11 ± 0.87 m) as the lowest (Figure 4-5). All three patches in the Mid-eastern group were distributed in the lowest mean height class. The patches in the Channel Highway group were distributed in the patches of ten highest mean heights, except patch number 30 which was distributed in the middle height class (Figure 4-5).

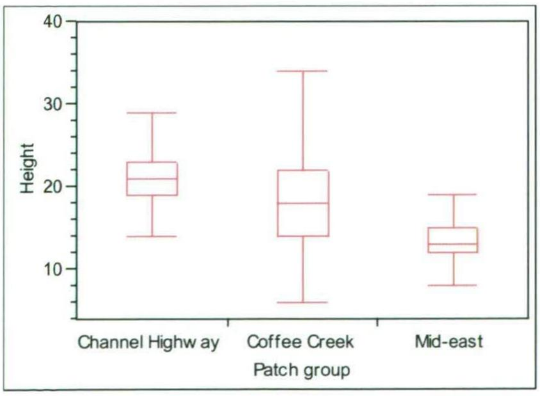


Figure 4-4 Mean height (m) in the three patch groups

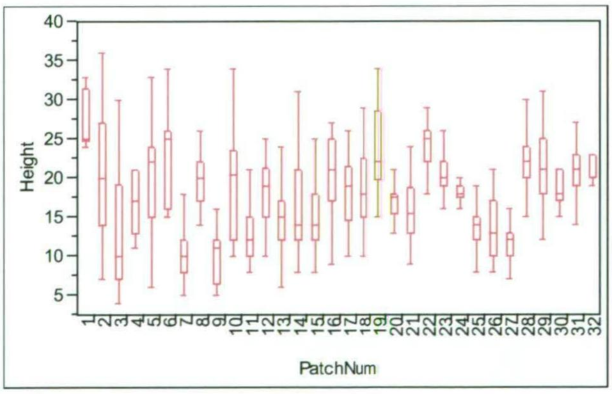


Figure 4-5 Mean height (m) at each forest patch
Coffee Creek: patch number 1 to 24, Mid-eastern: 25-27, and Channel Highway: 28-32.

Crown condition

The mean score of a combination of 3 single parameters (Size, Dead branches and Crown transparency = SDC) showed significant difference among the 3 groups (ANOVA, $F_{2,881} = 5.0964$, $P = 0.0063$). The highest mean score was found in the Channel Highway group (8.68 ± 0.19) and the lowest mean score was found in the Coffee Creek group (7.97 ± 0.10) (Figure 4-6). The mean score of the combined 3 parameters also differed significantly between individual patches (ANOVA, $F_{31,852} = 12.8937$, $P < 0.0001$). Patches 4 (11.4 ± 0.52), 1 (10.7 ± 0.83) and 24 (10.56 ± 0.68) showed the highest mean combination parameters score and patches 6 (6.6 ± 0.52), 3 (5.6 ± 0.51), and 7 (2.68 ± 0.38) showed the lowest mean score of the combined parameters. The three patches with the highest score and the three patches with the lowest score were located in the Coffee Creek group. All five patches in the Channel Highway group (patches 28 to 32) showed almost the same SDC score ranges (Figure 4-7).

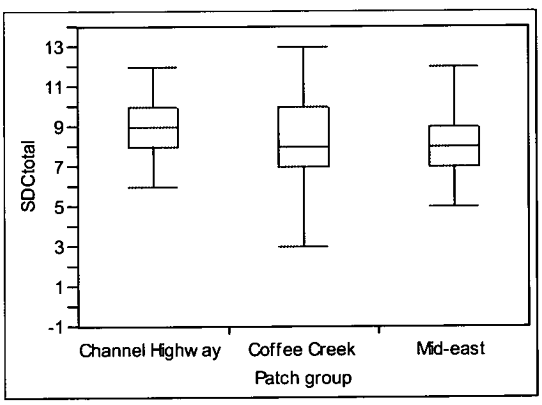


Figure 4-6 Mean score of a combination of 3 single parameters (Size, Dead branches and Crown transparency = SDC) in the three patch groups

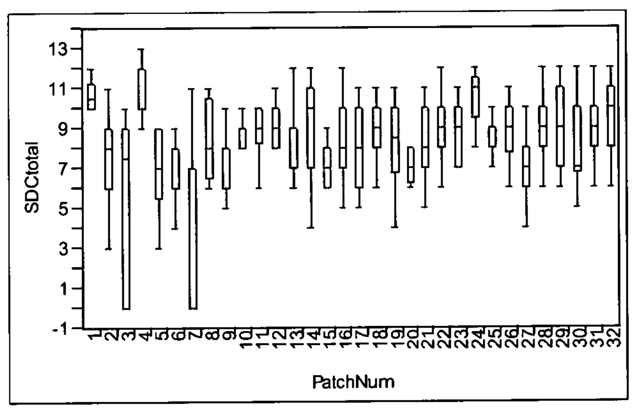


Figure 4-7 Mean score of combination of 3 single parameters (Size, Dead branches and Crown transparency = SDC) for each patch

Foliage damaged by insects

A total of 2,404 leaves were scored for their leaf area loss (percentage class) and different types of insect damage. Entire leaves (i.e. with no area loss) contributed the highest number with 498 (20.7 %) and the leaves with > 50 % area loss comprised the lowest number with 172 (7.2 %) (Figure 4-8).

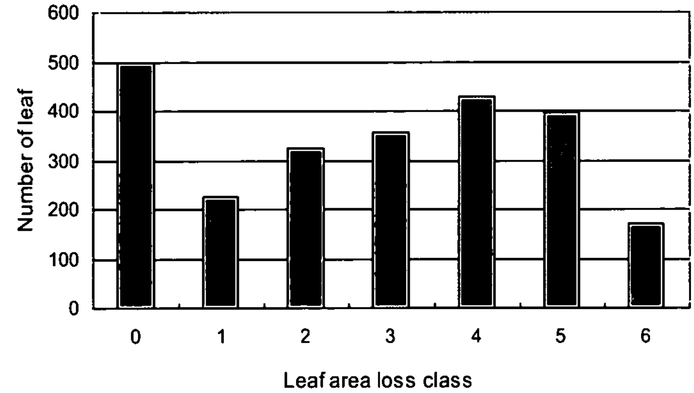


Figure 4-8 Number of leaves in each leaf area loss class (total = 2404 leaves)
0 = no leaf area loss; 1 = < 1%; 2 = 1-5%; 3 = 5-10%; 4 = 10-20%; 5 = 20-50%; 6 = > 50%

The mean score of leaf area loss showed significant difference among the 3 groups (ANOVA, $F_{2,2401}$ = 10.1460, $P < 0.0001$). The lowest mean score was found in the Channel Highway group (2.84 ± 0.10) and the highest mean score was found in the Mid-eastern group (3.48 ± 0.16) (Figure 4-9). The Channel Highway group and the Coffee Creek groups were not differentiated at $P < 0.05$ by the Tukey Kramer HSD test. At the patch level, there was a significant difference found in mean leaf area loss (ANOVA, $F_{31,2372}$ = 8.6826, $P <$ 0.0001). Patches 25 (4.12±0.24) and 9 (3.74±0.192) showed the highest score of mean leaf area loss and patches 22 (2.00±0.20), 2 (1.94±0.19) and 5 (1.28±0.16) showed the lowest mean score (Figure 4-10).

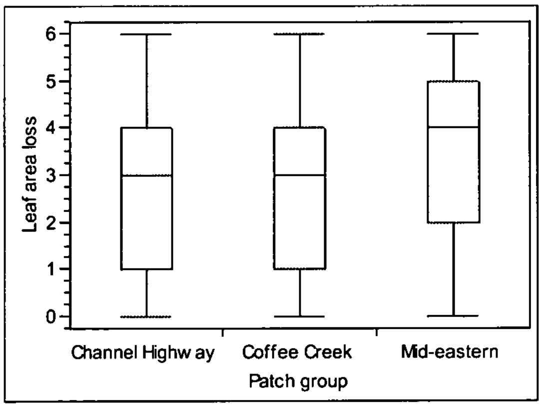


Figure 4-9 Mean score of leaf area loss in the three patch groups

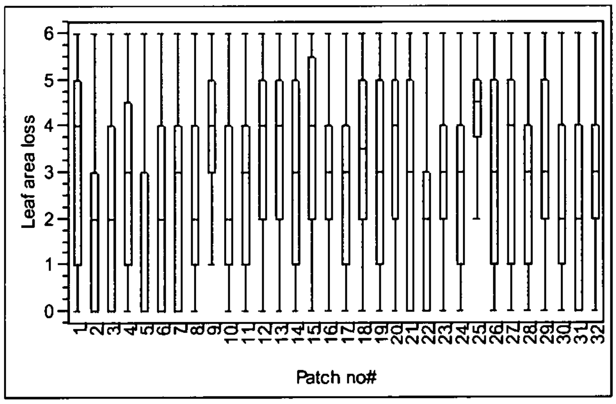


Figure 4-10 Mean score of leaf area loss at each patch

The proportion of leaf damage in each patch is presented in Figure 4-11. Chewing on the edges of leaves was the most widespread damage type seen and was typically found on more than 60% of leaves sampled. This is likely to be caused by insect larvae such as the caterpillars of moths and immature stages of beetles. In contrast, chewing of the interior of leaves was only found in 230 leaves of the total 2,404 (9.6 %). Surface erosion, as a damage type, was found in 1,095 leaves (45.5 %) and is usually associated with small caterpillars such as nolids and limacodids. Gall damage was found in 266 leaves (11.1 %), but no lerps were identified in the samples. Patch number 11 showed the highest proportion of gall damage, but was the lowest in erosion damage.

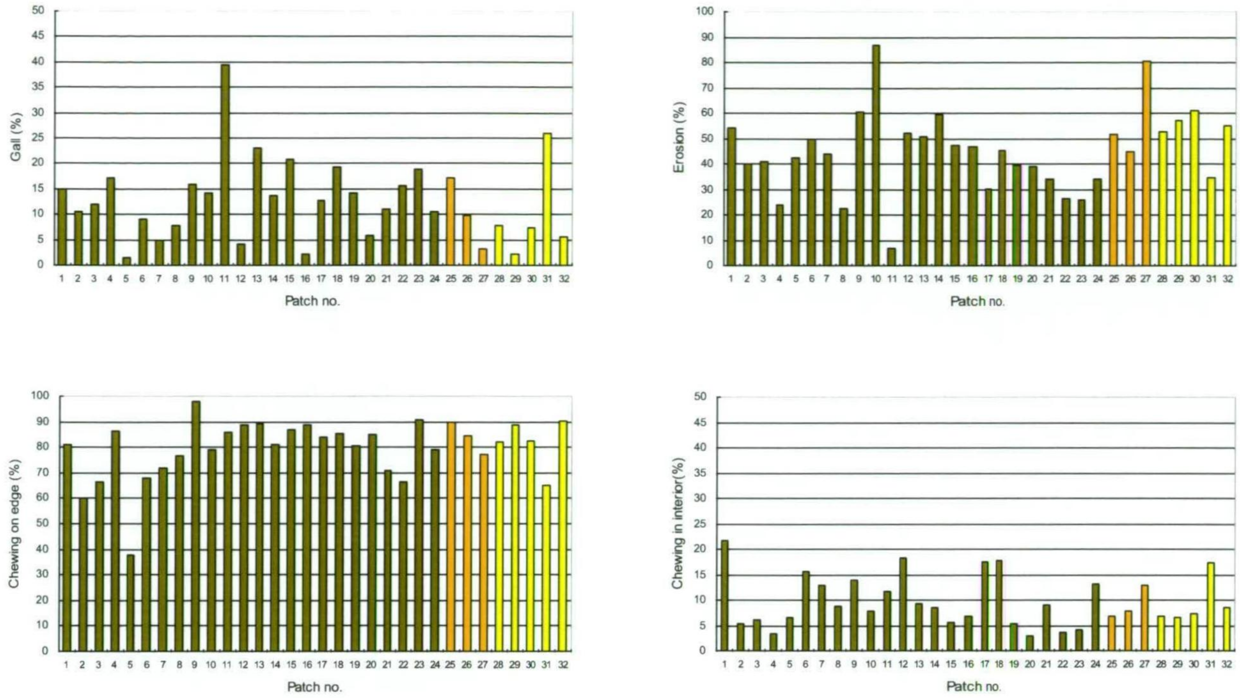


Figure 4-11 Proportion of leaves with each type of insect feeding damage Top: left) gall; right) erosion; Bottom: left) chewing on edges; right) chewing in interior. Colour of bars identifies different forest patch groups containing *E. viminalis* (green: Coffee Creek patch group; orange: Mid-eastern patch group; yellow: Channel Highway patch group).

4.3.2 Ordination of forest patch containing *E. viminalis* by patch attributes variables

A NMDS ordination of the forest patches containing *E. viminalis* was conducted based upon 26 environmental variables, including *E. viminalis* tree size, crown condition, leaf damage, canopy cover species and geographical features. This ordination produced separate Coffee Creek, Mid-eastern and Channel Highway patches (Figure 4-12). Coffee Creek patches were defined by low co-ordinate values on Axis 1, but these patches were widely scattered across Axis 2. Coffee Creek patches can be divided into two groups by the middle of Axis 2. The patches defined by a higher ordination value of Axis 2 were clusters on low ordination value of Axis 1, which includes CC16, 17, 18, 19, 20, 21, 22 and 23. This group is driven by maximum DBH and canopy cover of *E. obliqua*. Channel Highway patches were located in the top middle section of the ordination space, whereas Mid-eastern patches were concentrated on the bottom right section of the ordination space. The variable most strongly associated with the Channel Highway patches was canopy cover of *E. obliqua*. However, no single variable was strongly correlated with the Coffee Creek patches. The Mid-eastern patches are positioned higher in the local landscape and this explains their separation in the ordination.

A NMDS ordination of the forest patches based upon 9 variables focussed upon *E. viminalis* tree crown condition and leaf damage were tested. The result showed that all patches were clustered in the middle of Axis 2 and more scattered across Axis 1, except patches CC5 and CC11. *E. viminalis* tree crown condition and leaf damage can affect the abundance of food for *P. quadragintus*, therefore, the results assist our understanding of the associations with the bird detection rate. However, this ordination resulted in no strong patch grouping influenced by these variables alone (Figure 4-13).

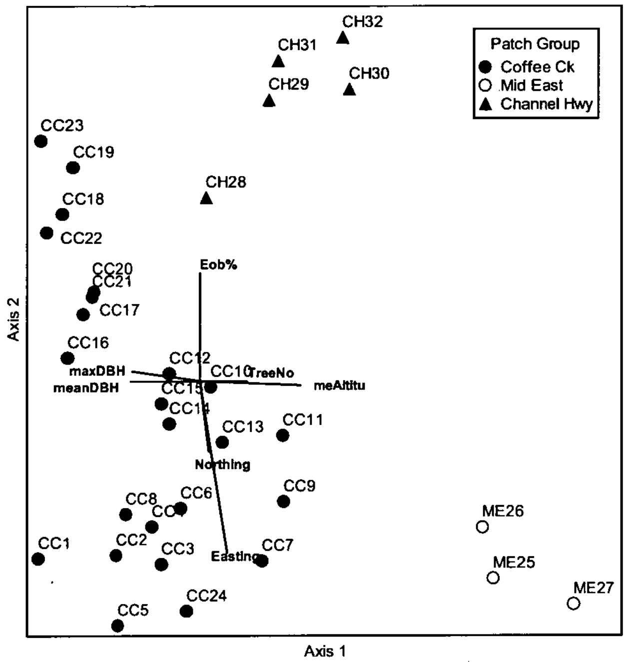


Figure 4-12 Ordination (NMDS) of forest patches based upon *E. viminalis* tree size, crown condition, and leaf damage, canopy cover species and geographical variables. Stress in 3 dimensions = 3.7%, cutoff R^2=0.200

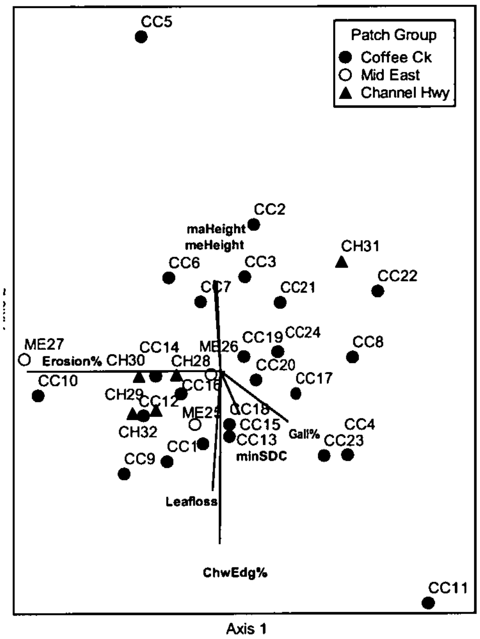


Figure 4-13 Ordination (NMDS) of forest patches based upon *E. viminalis* tree crown condition and leaf damage. Stress in 2 dimensions = 13.55%, cutoff R^2=0.200

The multivariate correlation analyses showed negative correlations between *E. viminalis* height and leaf area loss (r = -0.56) and chewing on edge (r = -0.67) (Table 4-1). A slight negative correlation was also found between the proportion of gall and erosion damage (r = -0.42). However, no strong correlation was found between crown condition and any category of leaf damage.

Table 4-1 Significant correlations ($P < 0.05$) among various measures of tree size dimension, crown condition and leaf damage

Variables	*r*
Mean Height – Leaf area loss	-0.5586
Mean Height – Chewing on edge	-0.6694
Gall – Erosion	-0.4186

4.3.3 *P. quadragintus* survey

P. quadragintus was recorded 13 times throughout my entire survey period from 3rd February to 8th September 2010, and 20 times during the previous *P. quadragintus* population survey from 3rd September

2009 to 3rd February 2010 (Bryant, 2010). The locations where *P. quadragintus* was detected are mapped in Figure 4-14. *P. quadragintus* was not recorded in the Channel Highway patches and Mid-eastern patches in the previous survey, but *P. quadragintus* were recorded at patches 29 and 31 in the Channel Highway group and patch number 26 in the Mid-eastern group during my study period. This is because the Channel Highway group and Mid-eastern group were newly described in my study and have not been included in previous *P. quadragintus* surveys. In the previous study, *P. quadragintus* was recorded 7 times outside of the *E. viminalis* patches (all detections were made in January 2010), which is located between Coffee Creek group and the Mid-eastern group. However, no *P. quadragintus* was detected at this location during my study period.

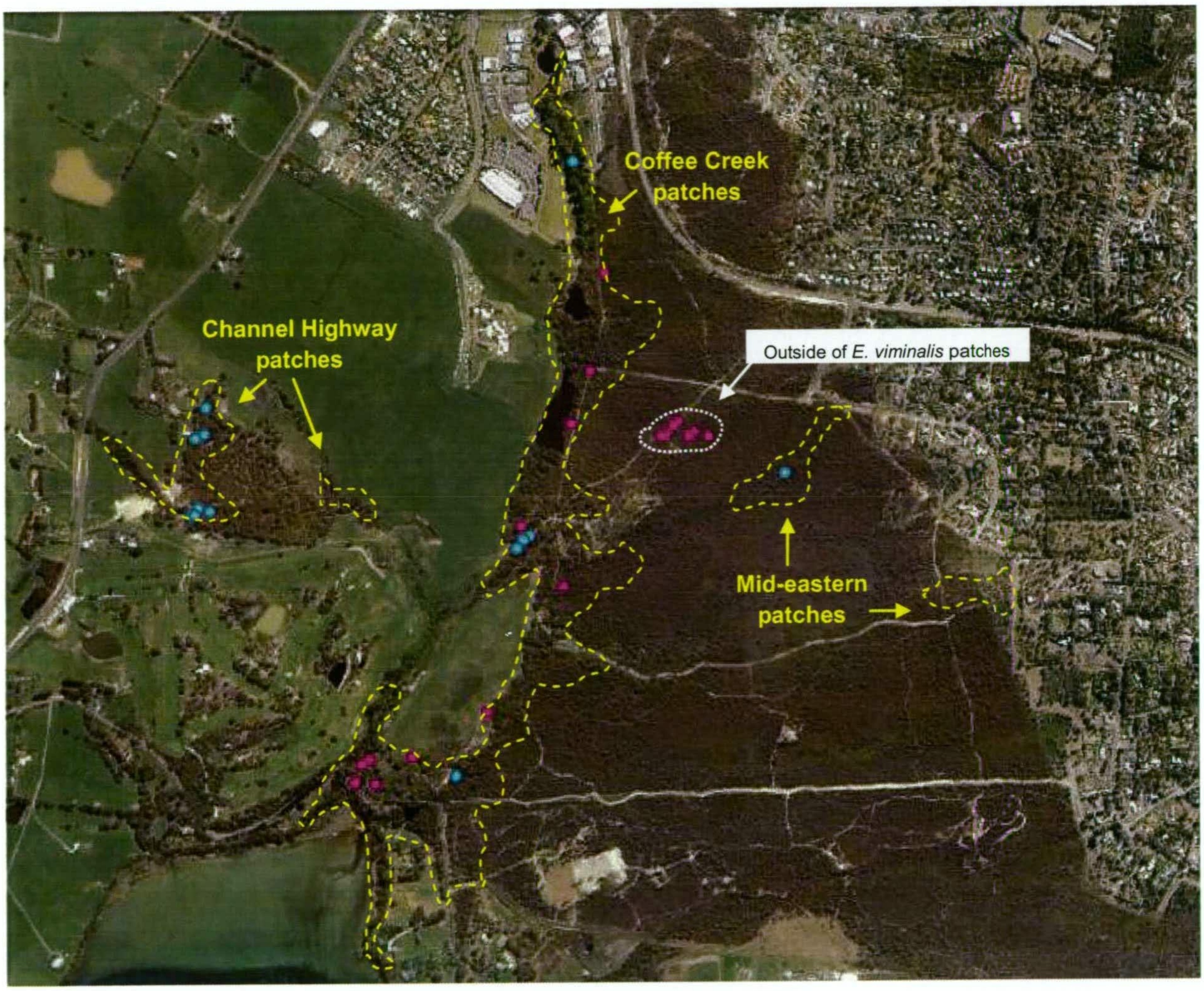


Figure 4-14 *P. quadragintus* detection map (Base photo: Google Earth, 2005)
pink dot = data from Bryant (2010), blue dot = data from surveys during my study

Each patch was visited between 2 and 12 times (Table 4-2). Patch number 31 showed the highest frequency of bird detection, with 100 %, followed by patch number 29 with 50 % and number 18 with 45.5 %. No *P. quadragintus* was recorded at 19 patches: 14 of 24 patches (58.3 %) in the Coffee Creek group; 2 of 3 patches (66.7 %) in the Mid-eastern group; and 3 of 5 patches (60 %) in the Channel Highway group.

Table 4-2 Ranked frequency of *P. quadragintus* detection at each *E. viminalis* patch
The four patches with the highest bird detection rate are shown in bold

Patch no.	No. of visits*	Frequency**		Total no. of birds detected***	Patch group
		no. of visits when bird detected	%		
31	**4**	**4**	**100.0**	**6**	**Channel Highway**
29	**6**	**3**	**50.0**	**3**	**Channel Highway**
18	**12**	**5**	**41.7**	**11**	**Coffee Creek**
9	**5**	**2**	**40.0**	**3**	**Coffee Creek**
12	10	3	30.0	3	Coffee Creek
23	4	1	25.0	2	Coffee Creek
16	5	1	20.0	1	Coffee Creek
20	6	1	16.7	2	Coffee Creek
26	6	1	16.7	1	Mid-eastern
7	7	1	14.3	1	Coffee Creek
2	8	1	12.5	2	Coffee Creek
10	9	1	11.1	2	Coffee Creek
13	12	1	8.3	6	Coffee Creek
1	5	0	0.0	0	Coffee Creek
3	3	0	0.0	0	Coffee Creek
4	6	0	0.0	0	Coffee Creek
5	8	0	0.0	0	Coffee Creek
6	6	0	0.0	0	Coffee Creek
8	5	0	0.0	0	Coffee Creek
11	2	0	0.0	0	Coffee Creek
14	6	0	0.0	0	Coffee Creek
15	3	0	0.0	0	Coffee Creek
17	4	0	0.0	0	Coffee Creek
19	4	0	0.0	0	Coffee Creek
21	3	0	0.0	0	Coffee Creek
22	2	0	0.0	0	Coffee Creek
24	2	0	0.0	0	Coffee Creek
25	6	0	0.0	0	Mid-eastern
27	7	0	0.0	0	Mid-eastern
28	4	0	0.0	0	Channel Highway
30	4	0	0.0	0	Channel Highway
32	3	0	0.0	0	Channel Highway

* no. of visits: the number of times that patches were visited and spent more than 10 min in this and adjacent patches (within 50m radius)

** Frequency: the number of visits during which *P. quadragintus* were detected and the rate for the detection (frequency rate (%) = frequency / no. of visits)

*** Total no. of birds detected: sum of the number of birds detected during all visits.

In patches 7, 13, 16 and 23 *P. quadragintus* was detected only in December (early summer), which is during the late breeding season and a time when the dispersion of juveniles can occur. In contrast, in patch number10 the bird was detected only in February, and in patch number 12 the bird was detected only in February (late summer) and April (early autumn). In patches 29 and 31, the bird was detected in June (middle winter) and September (early spring). In patches 7, 9, 10, 13, 16, 18, 20, 23, and 26, the bird was not detected in April and May (autumn) (Table 4-3)

Table 4-3 *P. quadragintus* detection month in each patch

Season		Summer		Autumn			Winter		Spring			Summer
		Non-breeding season						Breeding season				
Month		1	2	3	4	5	6	7	8	9	10	11	12
Patch number	2									D			
	7												D
	9										D		D
	10		D										
	12		D		D								
	13												D
	16												D
	18									D	D		D
	20									D			
	23												D
	26									D			
	29						D			D			
	31						D		D	D			

Yellow square: month for visit

D: *P. quadragintus* detected; Pink letter: result from Bryant (2010); blue letter: result from my study

4.3.4 Relationship between habitat attributes and *P. quadragintus* detection

A Principal Components Analysis (PCA) on correlations was performed on the patch attribute variables including the *P. quadragintus* detection rate, a total of 14 environmental variables. The first three components of the PCA accounted for almost two thirds (60.3 %) of the variation in the total dataset (Table 4-4) and these were examined further in respect of their eigenvectors to clarify which combinations of variables were the most influential (Table 4-5). The *P. quadragintus* detection rate was moderately loaded only on PCA 3 and was associated with southerly patch position and large trees at low altitude.

Table 4-4 Principal Components Analysis on correlations of 14 variables, showing eigenvalues and the individual and the cumulative percentage of variation explained.

Number	Eigenvalue	Percent	Cum Percent
1	3.5593	25.423	25.423
2	3.2185	22.99	48.413
3	1.6685	11.918	60.331
4	1.3867	9.905	70.236
5	0.9942	7.102	77.338
6	0.9524	6.803	84.141
7	0.8635	6.168	90.309
8	0.6485	4.632	94.941
9	0.3841	2.743	97.684
10	0.1544	1.103	98.787
11	0.093	0.664	99.451
12	0.0472	0.337	99.788
13	0.028	0.2	99.989
14	0.0016	0.011	100

Table 4-5 Eigenvectors (loadings) for each variable on the first three principal component axes. Absolute loading values which exceed 0.3 (indicating a statistically significant relationship) are shown in bold.

Variables	PCA1	PCA2	PCA3
Northing	-0.09444	**0.34342**	**-0.35088**
Leaf area loss	0.15302	-0.02644	0.12668
Mean DBH	-0.17014	**0.41259**	**0.39263**
Minimum DBH	0.08446	**0.45667**	0.02545
Maximum DBH	-0.10443	0.18337	**0.6251**
Mean height	**-0.46754**	0.14788	-0.01736
Minimum height	-0.18696	**0.32738**	-0.13322
Maximum height	**-0.4765**	0.10881	-0.02258
mean SDC	**0.35783**	**0.31404**	0.00931
Minimum SDC	**0.31165**	**0.3089**	-0.08611
Maximum SDC	**0.36002**	0.1883	0.15481
Mean Altitude	0.10142	0.2849	**-0.37667**
Mean Slope	0.22221	-0.11546	-0.06983
P. quadragintus	0.16011	-0.06387	**0.34423**

*SDC = sum of three parameters of Size, Dead branches and Crown transparency for crown condition

A NMDS ordination of the forest patches based upon canopy tree species did not separate into clear patch clusters (Figure 4-15). Most patches within all three groups were widely dispersed across the right half of the ordination space with a mixture of patches from all three groups. However, patches from the Channel Highway group were clustered in the top left of the ordination space, except patch number 30. The variable most strongly associated with the Channel Highway group was higher canopy content of *E. obliqua*.

In terms of the relationship between *P. quadragintus* detection and forest patch attributes, all of the six patches (CH29, CH31 and CC2, CC18, CC20 and ME26), except CC2, that *P. quadragintus* was detected in during September (early breeding season) were associated with canopy content of *E. obliqua.* The four patches (CC7, CC13, CC16 and CC23) that the bird was detected in only in December were strongly associated with canopy content of *E. amygdalina*, except CC23 which was highly associated with canopy content of *E. obliqua. P. quadragintus* detection month in each patch is shown in Table 4-3.

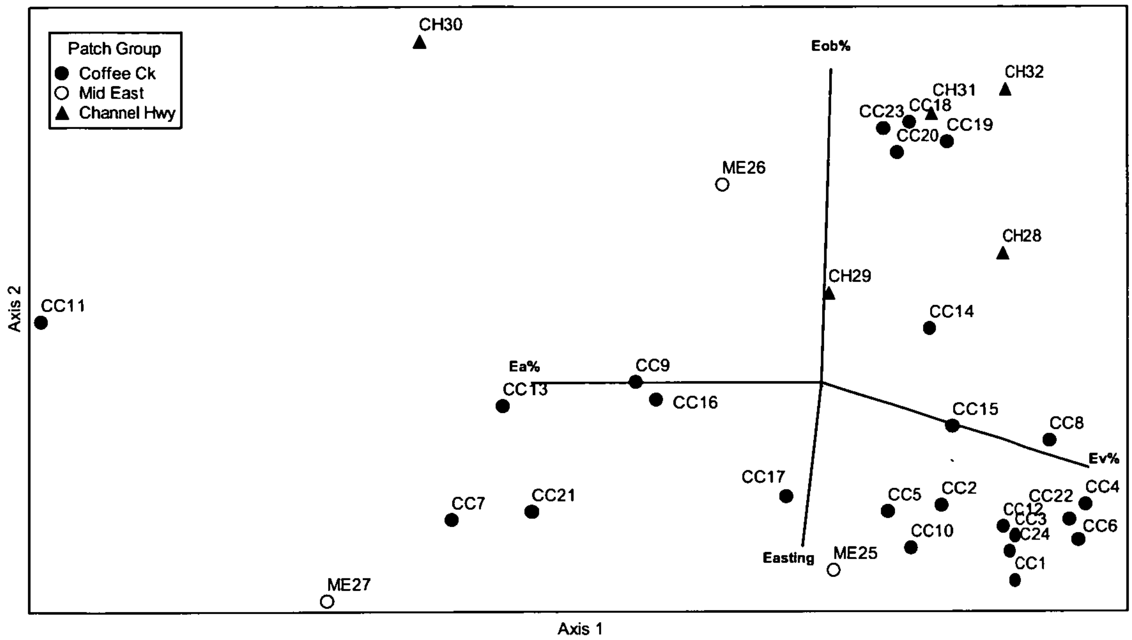


Figure 4-15 Ordination (NMDS) of forest patches based upon canopy tree species. Stress in 2 dimensions = 12.7%, cutoff R^2=0.200.

A Logistic Regression analysis that attempted to relate the occurrence (presence/absence) of *P. quadragintus* to a cross section of the measured environmental variables did not reveal any significant models. However, a Stepwise Regression model identified several environmental variables which, in combination, account for a component of the *P. quadragintus* detection rate (Adjusted R^2 = 0.6505, Table 4-6). This can be used to generalise the patch attributes where *P. quadragintus* was detected and provides a model for prediction of the detection rate of the bird. The results highlight the strong positive association of bird detection with a higher percentage of leaf damage caused by chewing insects which feed on the interior of the leaf. In terms of canopy cover, the *P. quadragintus* detection rate was positively associated with the presence of *E. obliqua* and *E. ovata* in association with *E. viminalis*, but negatively associated with *E. globulus*. In relation to *E. viminalis* size variables, DBH did not show any significance, while minimum tree height was positively associated, and minimum and maximum tree heights were negatively associated. This suggests that the *P. quadragintus* detection rate is at a maximum in *E. viminalis* patches with an average height of trees.

Table 4-6 Stepwise Fit model of *P. quadragintus* detection rate related to habitat and tree condition variables.

Variables	Estimate	nDF	SS	"F Ratio"	"Prob>F"
Easting	-0.0662	1	1336.359	8.344	0.0098
E. obliqua %	0.9342	1	2184.294	13.638	0.0017
E. ovata %	2.4356	1	1153.515	7.202	0.0152
E. globulus %	-7.5340	1	860.0836	5.37	0.0325
E. viminalis age structure (even or uneven}	8.6834	1	1336.277	8.343	0.0098
Mean Height	6.4989	1	1486.138	9.279	0.007
Minimum Height	-7.9797	1	3245.079	20.261	0.0003
Maximum Height	-2.7379	1	1188.843	7.423	0.0139
Chewing in Interior %	4.50447	1	6121.744	38.221	0

4.4 Discussion

4.4.1 Attributes of forest patches containing *E. viminalis*

Tree Size

The results of the *E. viminalis* tree DBH and height showed that the Channel Highway group had the highest mean DBH and height, while the Mid-eastern group had the lowest mean DBH and height. All five individual patches in the Channel Highway group had relatively similar size of trees and distribution in the medium size range among all thirty-two patches. All three patches in the Mid-eastern group also had a relatively similar tree size, but these trees were concentrated in the small size class among all patches. This contributed to the Mid-eastern group having the smallest mean tree size than other two patch groups. In contrast, mean tree size in the patches in the Coffee Creek group was evenly distributed across a wider range from the largest to smallest. These results may be influenced by the number of patches in each group and how the patches are distributed in the landscape. Twenty-four Coffee Creek patches were spread approximately 2 km from north to south and most of the patches are adjoining cleared land, which probably increases the opportunities to vary the environmental variables resulting in a wider range of mean tree sizes. In contrast, in the Channel Highway group all five patches were located within one small, and relatively round shaped, remnant forest surrounded by cleared land. Therefore, the Channel Highway group may have more consistent habitat characteristics and less variation in environmental attributes. In contrast, while all three of the Mid-eastern patch groups had similar sized small trees, the potential reasons for the *E. viminalis* trees with small tree size might be different between patches 25 and 26 (north section) and patch number 27 (south section). These two sections can be considered to be separated due to the lack of connectivity of *E. viminalis* stand between patches 25 and 26 and patch number 27 (approximately 400 m in distance). These two sections also consist of different types of vegetation communities. Patches 25 and 26 consist of a very high canopy tree density in a wetter environment (Chapter 2), which can create a highly competitive environment for nutrition resulting in a lower number of large trees (White & Harper, 1970). However, patch number 27 is located in a dry environment with a lower density of canopy trees. The potential reasons for a small *E. viminalis* tree size in patch number 27 may be the result of fire, because there are several large *E. viminalis* trees growing on private land adjoining this patch, as discussed later in this Chapter.

Crown condition and leaf damaged by insects

The highest scores for crown condition were found at patches 1, 4 and 24. These patches were the three smallest patches in size and isolated from other patches by a cleared area consisting of introduced grasses, bare ground and/or sealed surface. The better crown condition at these three patches may be a result of the higher water availability from runoff water and less competition for soil nutrients and water. Six patches with the poorest crown condition were found in the Coffee Creek patch group and five of these six patches (2, 3, 5, 6 and 7) are clustered together in the north of the Coffee Creek area. Patches 2, 3, 5, and 6 had the lowest leaf area loss, and other insect damage was in the middle range. Although no significant correlation was found between crown condition and insect damage of leaves, the above results may suggest that a poorer *E. viminalis* tree condition in these patches was not caused by insect damage.

The *E. viminalis* leaves in patch number 25 had a significantly higher leaf area loss damaged by insects in comparison to other patches, while crown condition was not significantly poorer. This result may suggest that in patch number 25 there is a lower abundance of insectivorous birds feeding on the insect larvae, such as the caterpillars of moths and the immature stages of beetles. A number of previous studies revealed that a decline in abundance of insectivorous birds reduces the tree crown condition due to an increase in the abundance of insects (Ford, 1981; Lockwood & Gilroy, 2004). Patch number 25 consists of a different vegetation community type, which is wetter than the other patches, has a higher canopy coverage (which could be indicative of higher tree density), and has a lower density of midstorey and understorey vegetation (Chapter 2). The structure of vegetation communities affects the abundance of insectivorous birds and species composition (Montague-Drake *et al.*, 2009). Therefore, patch number 25 may not be a preferable habitat for insectivorous bird species in the Howden region.

4.4.2 Habitat preference of *P. quadragintus*

Key habitat attributes for *P. quadragintus*

The result of the relationship between *P. quadragintus* detection rate and the proportion of *E. viminalis* canopy content and tree size did not show a strong correlation. This result was not consistent with the results of previous studies. Woinarski & Rounsevell (1983), Woinarski & Bluman (1985) and Brereton *et al.*, (1997) reported a positive correlation between the canopy cover of *E. viminalis* and the distribution of *P. quadragintus*. Bryant (2010) reported that large *E. viminalis* trees were a key habitat component driving territory size and bird density. One of the possible reasons for the inconsistent result of this study compared with previous studies is the limited amount of bird detection data available for statistical analysis. This is largely due to the very small *P. quadragintus* population size of small, quiet and cryptic birds, which are difficult to detect over a limited number of survey months.

However, more importantly this result may not just be attributable to a small sample size. It may suggest that the birds are not able to readily maintain their natural ecological behavior – of colonising habitat with a higher density of *E. viminalis*, including large *E. viminalis* trees, at Howden. This is probably because the birds are under significant and continuous pressure from human disturbance (e.g. high number of visitors, consistent noise, increasing edge affects) in a small reserve in a sub-urban landscape. The presence of competitors and the higher risk of predation caused by edge effects were not surveyed during this study. However, previous studies reported that the presence of competitors, such as *P. striatus* (striated pardalote) and *Melithreptus affinis* (black-headed honeyeater), can render habitat unsuitable for *P. quadragintus* (Cody, 1981; Woinarski & Bulman, 1985). Woinarski (1984) reported that honeyeaters selectively chase pardalotes because pardalotes are efficient harvesters of lerps that could otherwise be a major food source for honeyeaters. Predation risk is likely to be higher on the edge of the forest, because disturbance favours more aggressive birds, such as *Corvus tasmanicus* (forest raven), *Cracticus torquatus* (grey butcherbird) and *Dacelo novaeguineae* (laughing kookaburra). Therefore it is likely that *P. quadragintus* may avoid using the habitat along the forest edges, even when these habitats contain a higher abundance of food and large trees. For example, although patch numbers 1 and 8 include a high proportion of Class 4 trees, no *P. quadragintus* were detected. These two small patches are located on the edge of a cleared area. Patch number 1 is almost completely surrounded by an industrial estate, and patch number 8 is located close to a school, both of which are likely to be affected by consistent noise and visitors. There is almost no midstorey and understorey vegetation within these patches, which decreases shelter and increases predation opportunities. This would suggest unsuitable conditions for *P. quadragintus*, which favours relatively unmodified forest and increased security, which is enhanced in a habitat of increasingly larger size (Woinarski, 1986). The potential pressures from human related disturbance, as discussed in Chapter 3, is likely to be one of the main factors for the decline of the *P. quadragintus* population at Howden, rather than pressure from habitat quality (e.g. crown conditions, tree size, patch size). This suggests that these patches may not be favourable habitat for *P. quadragintus* despite them containing habitat of a suitable quality for the bird. As a consequence, under increased pressure from human related disturbance, *P. quadragintus* may be forced to use lower quality habitat, which likely differs from their favoured habitat. This may be one of the main reasons for no strong correlation between the bird detection rate and the abundance of *E. viminalis* and large *E. viminalis* trees in this study.

Although the survey month was limited, the result of the NMDS ordination may suggest seasonal habitat preferences by *P. quadragintus* driven by the canopy content of eucalypt tree species. All of the six patches (2, 18, 20, 26, 29 and 31), except patch number 2, in which the bird was detected in September, were associated with a canopy content of *E. obliqua*. In contrast, four patches (7, 13, 16 and 23), except patch number 23, in which the bird was detected only in December, were associated with a canopy content of *E. amygdalina*. These results may suggest that *P. quadragintus* use varied types of habitats in different seasons. September is early in the breeding season and the bird may prefer to use habitat with larger trees more likely to have hollows and produce large fallen limbs to provide nesting sites (Bryant, 2010). Although, non-*E. viminalis* trees have not been measured and recorded as part of this study, it was observed that the majority of *E. obliqua* in forest patches tended to be larger trees compared to other eucalypt species including *E. viminalis*. Bryant (personal communication, 2010) documents that forests containing only smaller *E. viminalis* trees may provide suitable habitat for *P. quadragintus* if that forest also contains larger eucalypt trees of other species. The large *E. obliqua* trees may provide nesting sites for *P. quadragintus* and/or create more shade and security, reducing exposure of the birds and their nests to predators. This may be especially relevant in habitat adjacent to cleared land, like most of the forest patches that contain *E. viminalis* at Howden. In contrast, December is late breeding season, and juveniles born in the early breeding season might already locally disperse from a parents' territory (S. Bryant, personal communication, 2010). From observations, the patches containing higher canopy content of *E. amygdalina* tend to include smaller *E. viminalis* trees and at a lower density.. The juveniles are easily disturbed and chased by other bird species, such as honeyeaters, and they are probably forced to occupy lower quality habitat (i.e. lower food availability and smaller *E. viminalis* trees). This may be one of the possible reasons for *P. quadragintus* being detected in the patches with higher *E. amygdalina* content in December. However, this result may also not indicate the true habitat preference of *P. quadragintus*, which may be forced to use a breeding habitat containing *E. obliqua* instead of a preferred habitat containing large *E. viminalis* due to higher abundance of competitors and/or high human disturbance pressures.

Regression Model

The results of the regression model can be used to generalise the patch attributes where *P. quadragintus* was detected and provides a model for prediction of the detection rate of the bird. Hence, the result does not suggest that each variable is individually associated with bird detection, but that the habitat contains a combination of variables which collectively may increase its attractiveness to *P. quadragintus*. The results of this study highlight the strong positive association of bird detection with a higher percentage of chewing damage in the interior of leaves. However, no linear association with leaf damage types, such as chewing on edge, erosion and gall was identified. The leaf damage profile suggests that edge-chewing larvae were probably the most common and abundant type on *E. viminalis* in this study site and contributed significantly to enlarging leaf area loss. *E. viminalis* trees with a higher level of leaf area loss may not be preferred habitat for *P. quadragintus*. This may be because these insects can reduce the abundance of lerps due to reducing the feeding space available for psyllid nymphs (P. McQuillan, personal communication, 2010). However, a higher level of leaf area loss indicates a higher abundance of caterpillars, which may be a winter resource for *P. quadragintus* in the absence of abundant lerps. In contrast, the insect larvae chewing the interior of leaves were less abundant. This result suggests that *P. quadragintus* may select a particular type of larvae chewing the leaf interior, which may be of a smaller size and therefore more suitable prey for the bird.

4.4.3 Estimated habitat size in Howden

Woinarski & Bulman (1986) estimated that the territory size of *P. quadragintus* was 0.7 ha, but their survey was undertaken on a single colony in a high density population on Bruny Island during the breeding season. Territory size may differ between colonies and seasons and depend upon the abundance of food. A *P. quadragintus* colony could be less than 0.5 ha in size with only 5 % of *E. viminalis* in canopy content to maintain a single pair of the species (S. Bryant, personal communication). Four forest patches 1, 4, 15 and 24, were less than 0.5 ha in size, but these patches are reasonably connected with the other patches, except patch number 24. Patches 1 and 4 also contain Class 4 *E. viminalis* trees. In contrast, patch number 24 is the smallest patch size (0.08 ha), containing no Class 4 *E. viminalis* trees and is completely separated from the remnant forest by human related disturbances (e.g. sealed street, buildings and cleared vegetation). As a result, patch number 24 is considered to have a very low possibility of being used by *P. quadragintus* as habitat, and therefore has not been included in an estimated habitat size for *P. quadragintus*.

In terms of their *E. viminalis* canopy content, patches 7, 21, and 27 may not be suitable for breeding habitat, because canopy contents of *E. vimianlis* were very low, with no Class 4 *E. viminalis* trees. Specifically, patch number 27 has less preferable conditions for *P. quadragintus* because this patch is completely isolated with few individual *E. viminalis* trees occurring between closest patches (Figure 2-7). The lower canopy content of *E. viminalis* recorded from patch number 27, which contained no Class 4 trees and the smallest proportion of Class 3 trees, may be the result of fire because several Class 3 and 4 *E. viminalis* trees grow on private land adjoining this patch. This suggests that the larger *E. viminalis* trees have possibly existed in patch number 27 in the past. In addition, a part of patch number 7 was burnt in 2010 under a schedule of prescribed burning which scorched some canopies of *E. viminalis* (photos of *E. viminalis* after the prescribed burning are shown Figure 6-2) and most of the other canopy trees (mainly *E. amygdalina*). As a result, although the majority of *E. viminalis* trees survived the fire, these trees were exposed through the loss of midstorey vegetation and surrounding smaller canopy trees. Russell *et al.* (2009) reported that prescribed burning increased the occupancy rates for several bark, ground and aerial insectivorous birds, but decreased the occupancy rates for foliage insectivores. In addition, if the fire intensity of a prescribed burning is too strong and burns a part of *E. viminalis* canopies, the result can directly affect the abundance of food for *P. quadragintus*, which may in turn lead to a decline in the bird population.

Those patches, in which no *P. quadragintus* were detected during the survey period between September 2009 and September 2010, may still be used by *P. quadragintus* for foraging and/or breeding habitats due to reasonable patch size and/or connectivity with other patches. Even the isolated patch number 27 may attract juveniles that locally disperse to this patch during winter for use as foraging habitat (S. Bryant, personal communication, 2010). This is very likely because the bird population in Howden is under significant pressure from human disturbance which may force birds to use lower quality habitat. As a consequence, the total habitat size was estimated at 40 ha (29 ha along Coffee Creek, 4 ha in Mid-eastern area of the Reserve, and 7 ha in the remnant between Coffee Creek and the Channel Highway). This is approximately 3.5 times bigger than the previous habitat estimation by Bryant (2010). The population size of *P. quadragintus* is routinely estimated by using measures of habitat size as an indicative guide. Based upon previous habitat sizes, the population of *P. quadragintus* at Howden was thought to be around 10 individuals. If the habitat is substantially larger than previously thought, then there is the possibility that the population of *P.*

quadragintus might also be larger. However, the extremely small number of birds detected during this study period, and the small number of birds detected during previous surveys, suggests that the estimated population size of 10 birds is likely to be accurate (S. Bryant, personal communication, 2010). Undertaking additional mapping of the distribution of *E. viminalis* forest and ascertaining accurate estimations of forest size are still important to determine the bird population survey area and prioritise land management planning. For example, the previous prescribed burning plan may need to be modified to exclude the potential bird habitat and adjacent area. Also existing land development plans need to be re-considered based upon the distribution of the potential habitat for *P. quadragintus*. Based upon the confirmation of the potential habitat location through this study, conservation actions are suggested in Chapter 6.

Chapter 5: Possible factors causing the decline of *P. quadragintus* populations

Remnant *E. viminalis* trees in the middle of golf course, 2010
Photo by C. Iijima

5.2 Introduction

5.1.1 Negative impact of urban and suburban development on native bird species

In urban and suburban landscapes rapid and extensive habitat fragmentation and direct human disturbance have been considered severe threats to native species diversity (Marzluff *et al.*, 1998). According to Andrén (1994: 355), "fragmentation is the process of subdividing a continuous habitat into smaller parts". In the suburban setting, habitat fragmentation is often caused by the expansion of housing and road development. Housing development reduces the habitat size by clearing remnant native vegetation and fracturing the connectivity of the habitat (Marzluff *et al.*, 1998). Housing development adjoining remnants can also contribute to a change in bird species composition by providing greater availability of food and water from domestic gardens (Ford, 1989). Because medium-sized bird species often gain a benefit from domestic gardens, there is likely to be an increased abundance of these species resulting in increased interspecific competition with small woodland birds (Ford, 1989). Roads affect bird communities over a wider area, mainly by altering the hydrology of an area resulting in alteration of habitat attributes. The presence of roads can lead to traffic victims among migrating animals, and they may fragment large populations into smaller ones which are more prone to extinction (Van der Zande *et al.*, 1980). Noise and air pollution caused by increased traffic can negatively affect bird populations. Habitat quality can be degraded by higher and more intense levels of human habitation and related activities, such as dumping rubbish, fir-wood taking and recreational use, adjacent to and within remnants.

Habitat fragmentation can cause edge effects that reduce bird dispersal and re-colonisation due to the creation of pockets of isolated habitat. Ultimately small local populations can become extinct due to the reduction in the immigration rate between local populations. Successive waves of local extinctions can have a critical detrimental impact on the survival of the whole population of the species (Ford *et al.*, 2001). Edge effects are defined as "changes in physical and biological conditions at an ecosystem boundary or within adjacent ecosystems" (Fischer & Lindenmayer, 2007: 271). Edges are typically subjected to a variety of degrading processes, for instance, microclimatic changes (e.g. temperature, humidity and wind speed) which may contribute to the reduction of food or foraging opportunities, input of soil nutrients, and invasion by weeds, domestic pets and feral animals. Edge effects also change biological variables such as fauna and flora species composition, and/or patterns of competition, predation and parasitism (Ford *et al.*, 2001; Fischer & Lindenmayer, 2007). In Tasmania, the aggressive *Manorina melanocephala* (noisy miner) has derived a benefit from fragmented habitats and invaded remnant patches of native vegetation in urban landscapes driving out the smaller bird species from the remnants, especially insectivores (MacDonald & Kirkpatrick, 2003).

Human direct disturbance can also be a threat to woodland bird species. It is recognized that one of the main outcomes of human disturbance is a change in bird species composition, such as a shift from predominantly native species to introduced species due to increased environmental degradation (Blair, 1996; Heileman, 2007; MacGregor-Fors, 2008). This is because many native species are intolerant of human activities and the resulting scarcity of natural habitat that accompanies urban development (Marzluff *et al.*, 1998). Specifically, small insectivores are intolerant of human activities and are more commonly found in the middle of larger sites, making them more reliant on large expanses of undisturbed habitat (Ford *et al.*, 2001). These species usually decline following vegetation change, because larger and more aggressive native and introduced bird species adapt well to new vegetation and subsequently displace smaller birds (Parsons, undated). Reproductive success may also be negatively affected by human direct disturbance. Van der Zande *et al.* (1984) reported that the density of half of the breeding bird species was negatively related to the intensity of recreational activities in urban forests in the Netherlands. The results suggested that even habitats that have abundant food can be unsuitable for small woodland bird species due to the effects of recreational activities.

5.1.2 Significance for examination of the effects of human disturbance on *P. quadragintus*

The *P. quadragintus* population at Howden is a small localised population, and the amount of habitat is very restricted by the suburban landscape. The results discussed in Chapter 3 suggest that the decline of the *P. quadragintus* population at the Coffee Creek habitat was not likely to be linked to *E. viminalis* crown condition. Potential causal factors of decline of the *P. quadragintus* population at Coffee Creek listed in Chapter 3 are:

1) Increases in adjacent residential development in the surrounding environment has resulted in isolation of the habitat and elevated levels of human disturbance;
2) Increases in human recreational activities have resulted in higher impacts to Coffee Creek and adjacent habitat;
3) Increases in edge effects resulting in a higher number of aggressive birds and predators; and
4) Increases in interspecific competition that reduces the food source and territory of *P. quadragintus*.

The expansion of development in areas adjacent to Coffee Creek may also contribute to intensifying the impact of the last three causal factors.

In winter *P. quadragintus*, particularly juveniles, disperse from core colonies, expanding to an area probably ten times as large (Hinton *et al.*, 1981). Dispersal may be a response to a seasonal decline in food availability within the core habitat during the winter months (Brown 1986; Woinarski & Bulman, 1986; Dorr, 1999). Although no study has confirmed the dispersion of the *P. quadragintus* population over Tinderbox Peninsula, Howden and Bruny Island, Brown (1986) reported that juveniles may disperse from Bruny Island to adjacent areas on the Tasmanian mainland. This suggested that *P. quadragintus* might have immigrated from Bruny Island habitats to Tinderbox peninsula and Howden habitats. Woinarski & Rounsevell (1983) reported that *P. quadragintus* employs a strategy to conserve its population size by maintaining a number of 'safe' large colonies which periodically recruit birds to smaller habitats. Under this scenario, North Bruny Island populations could be the source of recruiting birds to the Tinderbox Peninsula and Howden habitats (Figure 5-1). Therefore, the increasing isolation of the Howden habitat could contribute to the decline of the *P. quadragintus* population by preventing dispersion from other larger populations. In this sense, it could be acting as a sink for the species. An increase in interspecific competition can also be a severe threat to *P. quadragintus* because the species is strongly aggressive towards other pardalote species, especially *P. punctatus*. Chasing other bird species reduces their own foraging time and energy, which can contribute to a decline in reproductive success of *P. quadragintus* (Hinton *et al.*, 1981; Woinarski & Bulman, 1986).

The main aim of this chapter is to examine the development-related factors which may have caused the decline of *P. quadragintus* populations at Howden over the last 10 years by investigating housing and road development adjacent to the Reserve. The results will be used to make recommendations for the conservation management of the Howden *P. quadragintus* population in order to reduce the risk of local extinction of the species.

Figure 5-1 Location map of Howden, Tinderbox and Bruny Island populations (Google Earth, 2005)

Howden (area circled by yellow broken line), Tinderbox (area circled by green broken line) and the several colonies at the northern end of North Bruny Island including Dennes Hill, Water View Hill and 'Township' on (circled by red broken line).

5.2 Methodology

5.2.1 Study area

The study area is focused on land surrounding to the Peter Murrell Reserve and Conservation area, which includes parts of the suburbs of Kingston, Blackmans Bay, Howden, Huntingfield and Margate. A description of the Peter Murrell Reserve and adjoining area is contained in Chapter 2.

5.2.2 Disturbance survey

The dynamics of housing and industrial development and road establishment between 1989 and 2006 were surveyed using street atlases and aerial photos. This survey tracks the successive change in remnant size and isolation of habitat for *P. quadragintus*, and helps to better understand the potential causes of the declining *P. quadragintus* population at Howden. However, the negative effect of human direct disturbance on the *P. quadragintus* population is difficult to identify because there is no official record of visitation numbers or types of activities. So any correlation between declining *P. quadragintus* and population visitation and human activities is difficult verify. A low detection rate and observation of *P. quadragintus* at Howden makes it even more difficult to identify the impact of human direct disturbance. Visitors to the Reserve are mainly local residents (Parks and Wildlife Service, 2006), so that an increasing number of houses adjacent to the Reserve is likely to correspond to an increasing number of people visiting in the Reserve. As a result, expansion of housing and road development adjacent to the Reserve are used as indicators to understand the increase/decrease in human activities in the Reserve.

The dynamics of housing, industrial and road development between 1990, 1998 and 2005 were measured by comparing the number of buildings and roads/streets shown in the Tasmanian Towns Street Atlas (Department of Environment & Planning, 1990; Department of Environment & Land Management, 1998; TASMAP, 2005). The survey area in the atlas was selected to include an area within approximately 1 to 1.5 km spreading outward from the formal boundary of the Reserve. Grid lines with 500 m intervals on the map were used to outline the boundary of the survey area. The total area size is 1,425 ha, which was divided into four sections: North, East, South, and West (Figure 5-2 and Table 5-1). All buildings and roads/streets (larger than 'narrow road or private access'/'Lane or vehicular track' showing in the legend in the street atlases) were counted in each square (500 m x 500 m). Also, a measure of the frequency of development was obtained by counting the number of individual 500 m x 500 m squares (one quarter hectare) containing *any* buildings or road/streets to identify the expansion of these activities in the area.

Aerial photos taken in 1989, 1992, 1995, 1996, and 2006 (TASMAP) and 2005 (Google Earth) over the Reserve and surrounding areas were used to validate the results from the street atlas, by providing independent visual images of the expansion of housing and road development.

Table 5-1 Summary of the sections for the Atlas disturbance survey

Section	Suburbs	Area size (ha)	Number of 500 m x 500 m grid squares	Aerial Photos*
North	Kingston and Blackmans Bay	375	15	Figure 5-6
East	Blackmans Bay and Howden	325	13	Figure 5-6
South	Howden and Blackmans Bay	350	14	Figure 5-7
West	Huntingfield, Margate and Howden	375	15	Figure 5-8

* Aerial photos show part of each section

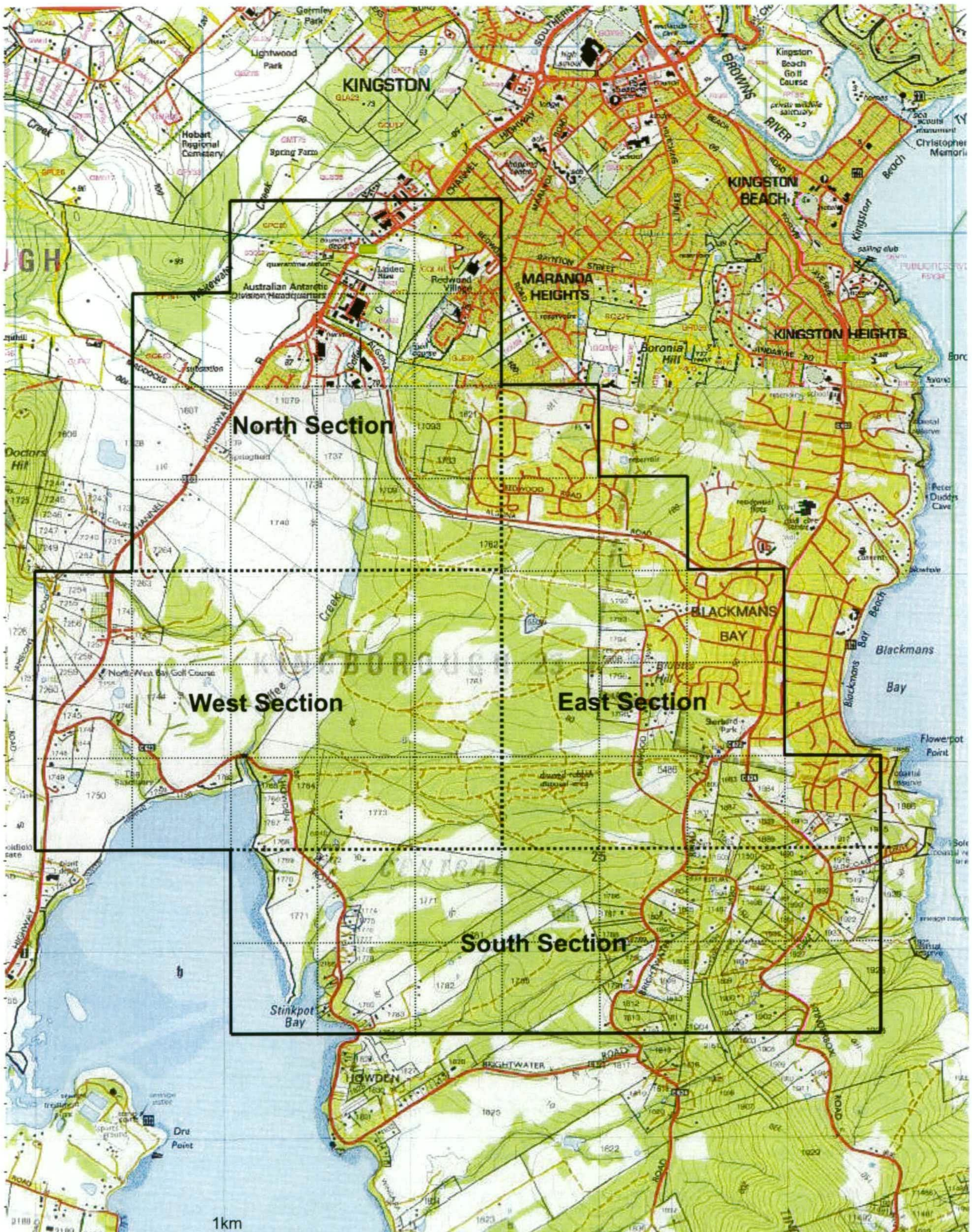


Figure 5-2 Section map for building and road development survey

— Boundary of the survey area, ······· boundary of section, ············ 500 m grid line

5.3 Results

Street Atlas

The number of buildings and roads increased from 1990 to 1998 and again to 2005. The number of buildings increased by 32.5 % from 1990 to 1998 and by 49.3 % from 1990 to 2005. The number of roads increased by 18.2 % from 1990 to 1998 and by 31.1 % from 1990 to 2005 (Figure 5-3).

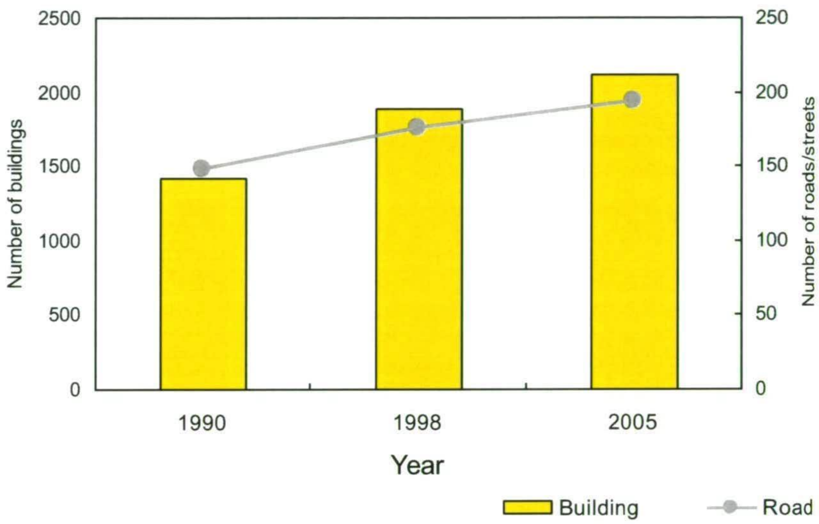


Figure 5-3 Number of buildings and roads/streets

The East section showed a higher number of buildings and roads compared to the other 3 sections. The second highest number of buildings and roads was found in the North section and the lowest was found in the West section (Figure 5-4 and Figure 5-5). The highest increase rate in buildings occurred in the North section by 95.3 % from 1990 to 2005, which is almost double the number of buildings. In contrast, the frequency of buildings– which is the number of grid squares including at least one building – showed the highest rate of increase in the South section from 8 squares in 1990 to 14 squares in 2005. The South section also showed the highest increase frequency rate in roads from 9 in 1990 to 11 in 2005 (Figure 5-4 and Figure 5-5).

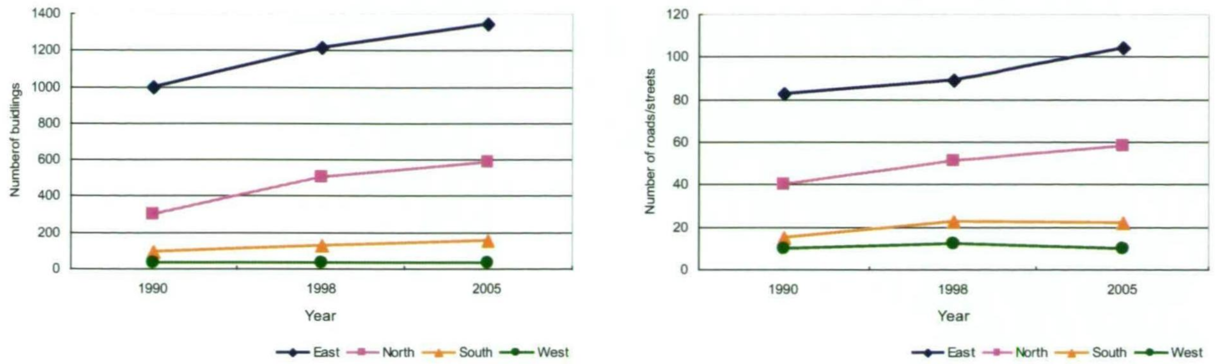


Figure 5-4 Number of buildings and roads: left) buildings, right) roads

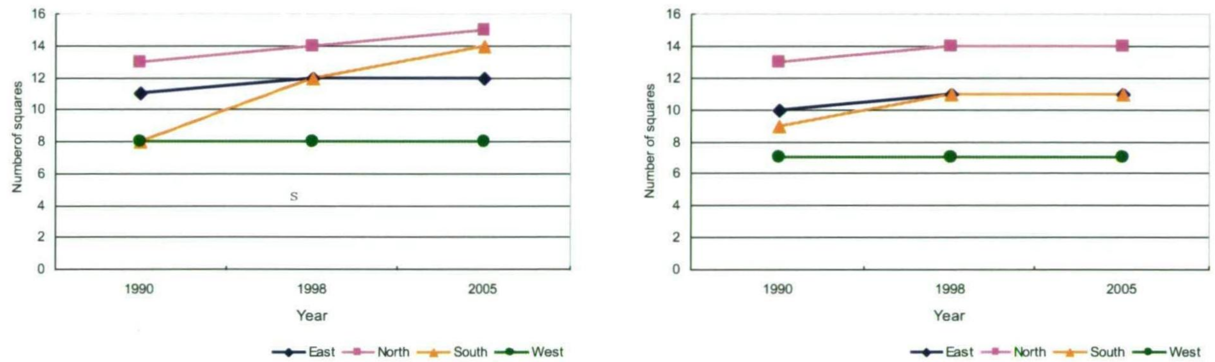


Figure 5-5 Frequency of buildings and roads: left) buildings, right) roads

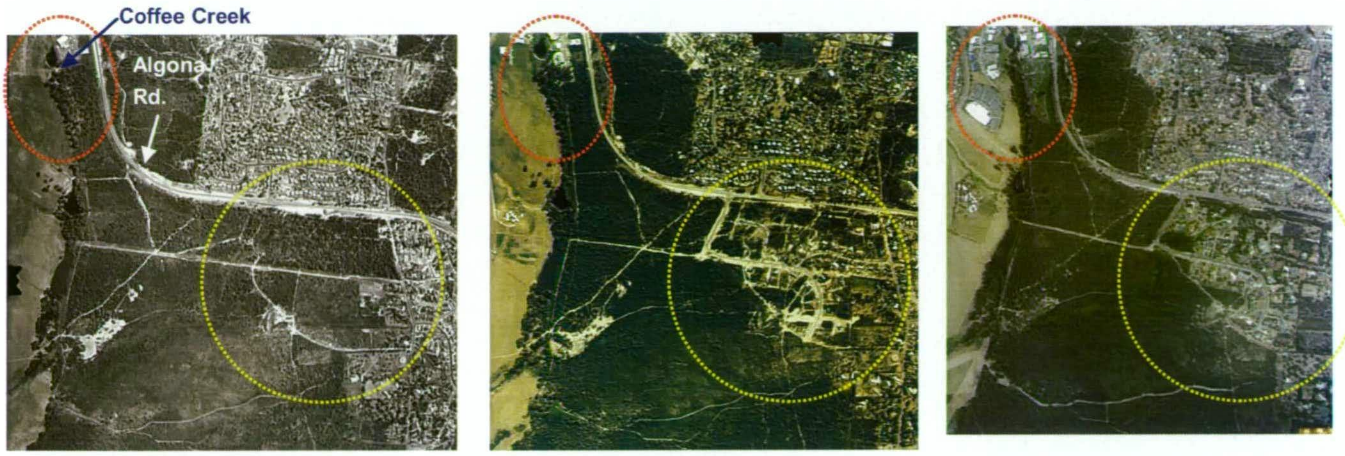
Aerial photos

North

Extensive development was identified to the north of the Reserve (between Algona Road and the northern end of Coffee Creek), particularly in the form of industrial development between 1995 and 2006. This area corresponds to the North section of the street atlas survey. As a consequence, only a very narrow strip of vegetation situated between the industrial area on the eastern side and a cleared patch of ground on the western side, was not subject to development along the banks of Coffee Creek (area circled by red broken lines) (Figure 5-6).

East

The expansion of residential and industrial development was identified in the northern and middle section of the aerial photos between 1989 and 2006 (Figure 5-6). Higher levels of residential development occurred in the mid-eastern section of the photos (the area circled by yellow broken lines) through 1989 to 2006, resulting in a reduction of remnant area connected with the current Reserve land between 1989 and 1995. This area corresponds to the East section of the street atlas survey. Three forest patches containing *E. viminalis* (patches 25, 26 and 27) were found close to this developed area and two of them (patches 25 and 27) are located adjacent to the formal boundary of the Reserve (Figure 2-7). Several Class 3 (DBH = 45-90 cm) and class 4 (DBH > 90 cm) trees were observed on private land adjoining patch number 27.



1989 1995 2006

Figure 5-6 Aerial photos taken in 1989, 1995 and 2006 of north and middle sections of the Reserve

South

The aerial photos in the south of the Reserve showed a big increase in housing development between 1992 and 2006 (area circled by a red broken lines) resulting in a decline and fragmentation of remnant bushland. This area corresponds to the South section of the street atlas survey. A wide fire break, which is also used as the formal reserve boundary, was identified in the photo taken in 2006, which can contribute to reducing the connectivity of the habitat between the Reserve area and the adjacent remnant bushland (Figure 5-7). The complex network and frequent number of small tracks used for horse riding have been established around the clear patch used by a pony club located in the left middle section of the photos (area circled by a yellow broken line).

1989 1992 2006

Figure 5-7 Aerial photos taken in 1989, 1992 and 2006 in the south section of the Reserve and adjacent area

West

The remnant forest and a golf course located between Coffee Creek and the Channel Highway did not show any noticeable difference in size between 1992 and 2005 (Figure 5-8). This area corresponds to the West section of the street atlas survey.

1992 2005

Figure 5-8 Aerial photos centered on Northwestbay Golf Club taken in 1992 and 2005

5.4 Discussion

The results of the street atlas survey clearly show a noticeable increase of around 50 % in the number of buildings and roads/streets from 1990 to 2005. This suggests a similar increase in the human population and therefore an increase in the number of visitors to the Reserve has likely occurred in last 20 years. Anecdotal evidence from a regular visitor to the Reserve confirms a large increase in visitor numbers to the Reserve (D. Abbott, personal communication, 2010). The rapid increase of buildings and roads is primarily the result of the expansion of two suburbs, Kingston and Blackmans Bay. In fact, the Kingborough municipality, which includes the study area, has been one of the most rapid population growth municipalities in Tasmania between 2004 and 2009 (Australian Bureau of Statistics, 2010). The wave of these developments has occurred on vegetation which probably included *E. viminalis* stands, to the boundary of the Reserve. Evidence of *E. viminalis* stands outside the Reserve was identified on private land adjoining patch number 27. The land has several Class 4 size (DBH > 90 cm) *E. viminalis* trees, which suggests that the forest/woodland with *E. viminalis* had extended to private land before the area was cleared for housing.

In the South section, while the number of buildings and roads/streets is low compared to the North and East sections, and did not show a large increase, the frequency of buildings and roads showed the highest increase among all sections. This result suggests that the South section is unlikely to contribute to increased human population around the Reserve, but may contribute to the fracturing of the connectivity between the Howden and Tinderbox habitats by the expansion of housing and road development. This can threaten the sustainability of the small Howden population because fragmentation reduces immigration, dispersal success and population survival (Fischer & Lindenmayer, 2007). In general, isolated small populations without recruitment from other populations are at higher risk of extinction due to declining genetic viabilities, which in turn weakens the ability of the species to survive episodic events (e.g. disease). Hence, housing development may have contributed to a decline in the Howden population of *P. quadragintus* over the last 10 years by reducing immigration and dispersal success for juveniles.

The area to the west of the Reserve, which includes the small remnants with five *E. viminalis* patches (28 to 32) showed few change in the last 20 years. This is because approximately half of the area has been owned by the Northwestbay Golf Club and most of the rest of the area had previously been Crown land. This Crown land is now owned by State Government, which has ear-marked the land for housing development in the near future. The result of the *P. quadragintus* survey showed that this remnant has been used by *P. quadragintus* as a breeding site and supports an estimated population of 6 birds (S. Bryant, personal communication, 2010), while the *P. quadragintus* detection rate has been significantly lower during the last 10 years in the habitat along Coffee Creek (S. Bryant, personal communication, 2010). Hence, protection of this remnant and cleared land from any development is critical to sustain the precarious *P. quadragintus* population at Howden.

The other potential negative effects of the housing development contributing to the decline of *P. quadragintus* are an increase in interspecific competition, predation opportunities and human activities. Some bird species can take advantage of the greater availability of nectar, fruit and water in domestic gardens in residential areas, resulting in an increase in the abundance of these species. These species are often medium-sized birds, such as the larger honeyeaters and parrots (Ford, 1989), especially *Melithreptus affinis* (black-headed honeyeater) which has been reported as a competitor of *P. quadragintus* (Woinarski & Rounsevell, 1983). An increasing abundance of *Corvus tasmanicus* (forest raven) has been observed by regular visitors to the Reserve (D. Abbott, personal communication, 2010), which increases the opportunity of predation on fledglings resulting in a decline of the *P. quadragintus* population.

Chapter 6: Conclusions and recommendations

Illustration by Tim Squires

6.1 Conclusions

A *P. quadragintus* colony was previously known in the *E. viminalis* stands along Coffee Creek, and a population survey was conducted only on this narrow strip of forest (Threatened Species Unit, 1998; Bryant, 2010). My study has confirmed the existence of additional *E. viminalis* stands within the Peter Murrell Reserve and Conservation Area and adjacent freehold and crown land. As a result of my survey, the total potential *P. quadragintus* habitat size is estimated to be 40 ha, which was more than three times larger than the previous estimation of 12 ha (Bryant, 1995). The forest containing *E. viminalis* consists of either pure *E. viminalis* stands or mixed with other eucalypts species, such as *E. amygdalina* and *E. obliqua*. Brereton *et al.* (1997) did not identify the forest/woodland containing *E. amygdalina* as potentially suitable habitat for *P. quadragintus* in their habitat modeling. However, *E. amygdalina* is the dominant, sub-dominant and co-dominant canopy tree species along with *E. viminalis* in this study area, and was identified in the Tinderbox colonies, the closest *P. quadragintus* colonies to Howden (Hinton *et al.*, 1981).

Bryant (2010) found that the total *P. quadragintus* population declined by 60 % since the population was first surveyed in 1986. The cause of this population decline may involve a number of complex factors, which may differ from colony to colony. For instance, in nearly every colony on Bruny Island *E. viminalis* trees appeared to be in decline and dieback is evident. This was considered to be the main factor contributing to a declining bird population in these colonies. In contrast, the habitat quality at Howden retains sufficient mature *E. viminalis* in good condition, yet the *P. quadragintus* population has halved from 20 birds to only 10 birds in the last 10 years (Bryant, 2010). To confirm this assessment, the habitat quality of *E. viminalis stands,* including crown condition, tree size and other environmental variables, was assessed in the Coffee Creek habitat at Howden, and on a private property called 'Township' on north Bruny Island. Neyland (1996) reported that *E. viminalis* in Tasmania is particularly sensitive to, and intolerant of, drought. Grice (1995) also reported that eucalypt decline in Tasmania is severe where the annual average rainfall is below 625 mm per annum. Over the last 15 years the precipitation records for the Howden and Bruny habitats exhibit similar year by year variable trends, while the annual average rainfall in both habitats has been below 625 mm. However, *E. viminalis* trees in the Coffee Creek habitat did not show significant decline, while those in the Bruny Island habitat did. The results suggest that the 'Township' habitat on Bruny Island is more susceptible to drought than the Coffee Creek habitat, probably due to a lower level of soil water holding capacity and less excess water availability. The result of the habitat quality survey was consistent with Bryant's report (2010) and suggested that the reasons for the decline of the *P. quadragintus* population at Howden may not be related to habitat quality. Rather, population decline may be caused by other factors, such as an increase in human related disturbance.

The habitat preference of *P. quadragintus* was examined by analysing the relationship between the bird detection rate and previously known habitat characteristics. Understanding the key characteristics of habitat quality is critical for designing habitat management strategies for bird species of conservation concern, such as *P. quadragintus,* to secure viable endangered species populations (Cameron & Cunningham, 2006; Lloyd, 2008). However, the result did not show any strong correlation between the previously recognised preferred habitat characteristics, such as canopy dominance of *E. viminalis* and the proportion of Class 4 *E. viminalis* trees (DBH > 90 cm), and the number of birds (Woinarski & Rounsevell, 1983; Woinarski & Bluman, 1985; Bryant, 2010). One possible reason for this is the limited amount of bird detection data for statistical analysis due to a very small *P. quadragintus* population size, detection difficulties of this small, quiet and cryptic bird, and a limited number of bird survey months. However, more importantly, this result may suggest that the birds are not able to establish their natural ecological behaviours in the Howden habitat because of a high level of human disturbance, such as high visitor numbers, consistent noise and increasing edge effects. Rapid expansion of housing development adjacent to the Reserve was confirmed through the atlas map survey. This result indicated a likely increase in human activities in the Reserve, and isolation of the habitat due to fragmentation of the vegetation.

The important finding of this study is that while the forest/woodland at Howden contains sufficient *E. viminalis* stands in good condition to satisfy the *P. quadragintus* ecological requirements, the local colony may well not be saved from extinction. The decline of the bird population at Howden is more likely to be as a result of increased pressures from human activities (e.g. walking, dog walking and trail bike riding) and a change in surrounding landscape (e.g. residential and industrial development, division of lands). These human related disturbances also increase habitat isolation and edge effects of *P. quadragintus* habitat. The end result is deterioration in high quality habitat for *P. quadragintus*, which is likely to have forced the bird to seek out lower quality habitats. Bryant (2010) reported that aggressive birds favouring disturbed environments (such as the grey butcherbird and the kookaburra) have increased in abundance and are becoming more widespread. This contributes to an increase in competition and a decrease in breeding success. Increasing isolation from other *P. quadragintus* colonies, such as those on the Tinderbox peninsula and on Bruny Island, probably reduces dispersal success and restricts colony size. Hence, considerable management of the surrounding landscape is essential for sustaining the *P. quadragintus* population at Howden, along with the protection and rehabilitation of their habitat to improve habitat quality. Although the task of saving this small local population appears increasingly difficult, it is nevertheless important to make every effort to save this colony, and the entire species, from extinction. A key to doing this is by improving their habitat quality through enlarging the areas of suitable habitat by planting trees and connecting habitats and by minimising human threats to the birds.

6.2 Recommendations

Recommendations for immediate conservation actions for the *P. quadragintus* population at Howden have been identified through the results of this study. In addition, this study has highlighted the need for further research to increase our knowledge and understanding of this species, its needs and threats.

Recommendations for immediate conservation actions

1. **Protect and rehabilitate the remnant forest owned by the State Government (Housing department), located between Coffee Creek and the Channel Highway.**

   The estimated *P. quadragintus* population size in this remnant forest is six birds (Figure 6-1: Recommendation 1), which is a high proportion in regard to the total estimated population of 10 birds in Howden. Because this remnant currently has no public access human activity is likely to be lower than that at the Coffee Creek habitat. Also the relatively circular shape of the remnant suggests a low edge ratio and less negative effects on the habitat. Nevertheless, evidence of human disturbance in the form of tree felling for firewood, dumping of rubbish and burning of vegetation have been observed in this remnant. To secure this area as *P. quadragintus* habitat these human disturbances need to be eliminated, and sympathetic land management of the cleared land that surrounds this habitat is essential. Linking the remnant forest with the Coffee Creek habitat by planting *E. viminalis* along a creek line (Figure 6-1:

Recommendation 1 – creek line) may provide a safer local dispersion route for the bird. Monitoring of the population also needs to be undertaken to evaluate the effect of these suggested actions, and increase our understanding of the territory size and distance for dispersal of *P. quadragintus*.

2. **Reduce the edge effects by planting trees and/or encourage regeneration of *E. viminalis* in the cleared area located between Coffee Creek and the Coffee Creek Fire Trail**

   Almost all the forest patches containing *E. viminalis* along Coffee Creek and along the adjoining cleared area (inside the Reserve), are likely to be affected by edge effects. Planting trees and/or encouraging regeneration of *E. viminalis* in the cleared area between Coffee Creek and the Coffee Creek Fire Trail (Figure 6-1: Recommendation 2) may improve this marginal habitat by providing shade and foraging habitat for future generations of birds. Reducing edge effects in this way can increase the favoured habitat size for *P. quadragintus*.

3. **Encourage local residents, school and the golf club to plant and/or restore *E. viminalis* in their property**

   Forest patches 19, 22 and 23 are on private land. It is very important to ensure that *E. viminalis* trees on private land are protected and not removed, because it is very likely that *P. quadragintus* use these stands for foraging and breeding habitat. Also the *E. viminalis* trees on private land may play a vital part in connecting isolated habitats by providing 'stepping stones', allowing the bird to disperse to a wider area. This can also present an opportunity to educate local people, including school children, about the importance of the conservation of this rare and endangered species, and to encourage them to play an active role in protecting the species through their direct involvement in conservation projects.

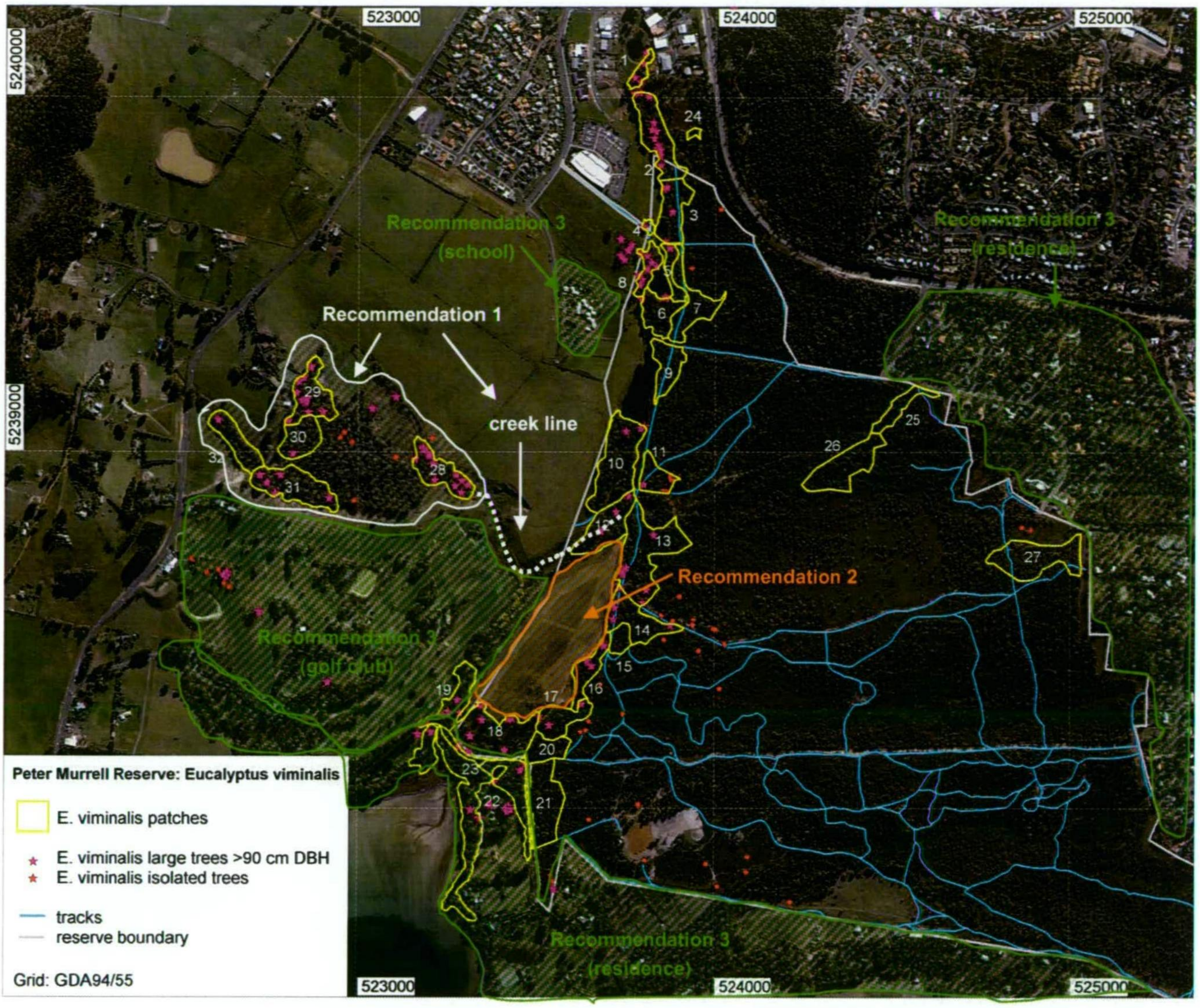


Figure 6-1 Map for each recommendation site
White margin: recommendation 1; orange margin: recommendation 2; green margin: recommendation 3.

4. **Re-consider the prescribed burning schedule and area in the Reserve to prevent the reduction and deterioration of habitat for *P. quadragintus***

   Although the existing prescribed burning is designed to regenerate vegetation, maintain species diversity, reduce fuel loads and manage weeds (Parks and Wildlife Service, 2006), it comes at the risk of reducing the foraging habitat and possible nesting sites for *P. quadragintus*. Burning may also increase the vulnerability of habitat to wind and rain and change key habitat attributes. In April 2010 the prescribed burning undertaken at FRB3 (Scarborough) burnt most of the canopy trees, including several *E. viminalis*. This prescribed burning killed, or at least burnt a part of the canopy of *E. viminalis* (Figure 6-2). The blocks of land which contain *E. viminalis* for which the prescribed burning program has been scheduled to 2016 are listed in Table 6-1 (Figure 6-3). It is strongly recommended that the burning of these blocks be reconsidered in light of the threat to *P. quadragintus* habitat.

Figure 6-2 After prescribed burning at FRB3 (Scarborough) in 2010
Top: This photo shows the prescribed burning scorched canopy trees, which is the brown colour patch in the middle of the green patch; Bottom: the prescribed fire scorched most of the canopy of this *E. viminalis*

Table 6-1 Prescribed burning blocks that include *E. viminalis* patches

ID	Block Name	Schedule	*E. viminalis* patch no.
FRB4	Middle West	2012	13
FRB5	Middle East	2014	26
FRB6	Howden	2016	14, 15
block1	Sandflats	Post 2016	9, 11
block3	Bracken	Post 2016	11, 25
block6	Pony Club	Post 2016	21

* ID, block name and schedule were acquired from Parks and Wildlife Service (2006)

Figure 6-3 Map of prescribed burning program (Parks and Wildlife Service, 2006)

Suggestion for further studies

1. Develop a monitoring program as part of a broader conservation management plan for Howden

A monitoring program can also increase opportunities to understand *P. quadragintus* behaviour under disturbance pressures and learn more about the causes of decline in the bird population. This knowledge can then be applied to other local populations to ensure their protection and conservation. Bryant (2010) suggests that one possible action that might be taken in the future to assist the *P. quadragintus* population to recover is to relocate birds to potentially viable habitats where birds have previously occupied. If bird re-location is going to be undertaken in the future, the Howden population may be considered as one of the possible population sources for new colonies. This is especially relevant if the Howden population continues to face long term pressures resulting from a rapid increase in human induced disturbances (S. Bryant personal communication, 2010). For this reason, continuous monitoring of the bird population at Howden may prove useful to the success of any species re-location in the future.

2. **Identify the effect of human recreational use on *P. quadragintus*, such as trail bike riding and off-leash dog walking**

   Based upon the results of the studies, seasonal restriction of the Coffee Creek Fire Trail for walking and trail bike riding in the area close to Coffee Creek may be considered as one of the options to reduce the impact on the bird population.

3. **Conduct a *P. quadragintus* population survey in different seasons**

   Further surveys can increase the chances of bird detection and therefore give a more accurate population figure, as well as increasing understanding of their seasonal habitat preference.

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Appendix 1: Patch boundaries

Western boundary of patch no.2 and no.3

Patch no. 4

Patch no. 5

Patch boundary between no.6 and no.9

Patch boundary between no.7 and no.9

Patch boundary between no.10 and no.12

Patch boundary between no.13 and no.14

Patch boundary between no.14 and no.15

Parch boundary between no. 18 and 22 (Howden Road)

Patch no.24

Patch boundary between no.29 and no.30

Patch boundary between no.31 and no.32

Appendix 2: *Eucalyptus viminalis* patch data

Patch no.	Patch groups	Area (ha)	Easting	Northing	No. of tree surveyed	*E. v.* age structure	Aspect	Soil type
1	Coffee Creek	0.314	523788	5240080	6	un-even	SE	sand
2	Coffee Creek	1.631	523841	5239803	39	un-even	SE	sand
3	Coffee Creek	1.269	523885	5239681	16	un-even	SE	sand
4	Coffee Creek	0.105	523811	5239634	15	un-even	E	sand
5	Coffee Creek	0.449	523867	5239512	8	un-even	SW	sand
6	Coffee Creek	0.975	523853	5239392	15	even	S	sand
7	Coffee Creek	1.297	523949	5239450	28	un-even	SW	sand
8	Coffee Creek	0.572	523811	5239518	13	un-even	SW	sans
9	Coffee Creek	0.961	523869	5239225	17	un-even	S	sand
10	Coffee Creek	2.434	523724	5238970	20	even	SW	sand
11	Coffee Creek	0.731	523809	5238956	6	un-even	S	sand
12	Coffee Creek	1.440	523688	5238795	17	un-even	S	sand
13	Coffee Creek	2.830	523828	5238721	82	un-even	N	sand
14	Coffee Creek	1.395	523806	5238536	35	un-even	S	sand
15	Coffee Creek	0.404	523722	5238471	19	even	S	sand
16	Coffee Creek	0.798	523649	5238361	21	even	S	sand
17	Coffee Creek	0.994	523580	5238244	16	un-even	S	sand
18	Coffee Creek	2.511	523384	5238216	30	un-even	S	sand
19	Coffee Creek	1.052	523291	5238313	18	un-even	SW	sand
20	Coffee Creek	0.732	523534	5238164	12	even	SW	sand
21	Coffee Creek	1.892	523527	5238014	63	un-even	N	sand
22	Coffee Creek	1.250	523427	5238064	21	even	SE	sand
23	Coffee Creek	2.954	523320	5237958	24	un-even	W	sand
24	Coffee Creek	0.078	523940	5239898	9	even	SW	sand
25	Mid-east	0.623	524511	5239127	79	un-even	S	sand
26	Mid-east	1.684	524439	5239040	38	un-even	S	sand
27	Mid-east	1.986	524898	5238705	68	even	NW	sand
28	Channel Highway	1.304	523237	5238957	43	un-even	SE	sand
29	Channel Highway	1.374	522866	5239172	35	even	E	sand
30	Channel Highway	1.000	522833	5239042	18	un-even	E	sand
31	Channel Highway	1.790	522819	5238898	36	un-even	E	sand
32	Channel Highway	1.035	522655	5239026	17	even	E	sand
Isolated					72			

Appendix 3: Dominant plant species in each patch

	Coffee Creek																											Mid-east						Channel highway								Total		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean (%)	Frequency		25	26	27	Mean (%)	Frequency		28	29	30	31	32	Mean (%)	Frequency		Mean (%)	Frequency	
Canopy																																												
eucaamyg	5	10	5		10		20		30	15	70	5	30	5	5	35	25			5	15		5	5	16.7	18	75%	15	30	15	20.0	3	100%		10	40			25.0	2	40%	12.8	23	72%
eucaglob																										0	0%					0	0%					5	5.0	1	20%	0.2	1	3%
eucaobli		10	5									5		15	5			25	35	40	5		40	5	17.3	11	46%		35		35.0	1	33%	30	15	30	40	45	32.0	5	100%	12.0	17	53%
eucaovat			5	5																		5			5.0	3	13%	20	5		12.5	2	67%					3	3.0	1	20%	1.3	6	19%
eucavimi	95	80	85	70	65	85	15	60	30	80	5	80	20	55	60	45	65	35	45	45	15	80	40	90	56.0	24	100%	65	35	10	36.7	3	100%	60	45	10	40	45	40.0	5	100%	51.7	32	100%
Middlestorey																										0	0%					0	0%							0	0%	0.0	0	0%
acacdeal	5	5	10		5	15	15				5	5	5	5		5	15	3	5		10				7.5	15	63%					0	0%	3				5	4.0	2	40%	3.8	17	53%
acacmela		10	20		10	25	10		20	10	5	15	25	15	5	5	15	5	40	15	5	20	10	10	14.0	21	88%		15	5	10.0	2	67%		3	3		10	5.3	3	60%	10.3	26	81%
acacvart																										0	0%					0	0%	5			5	5	5.0	3	60%	0.5	3	9%
allomoni																										0	0%			10	10.0	1	33%							0	0%	0.3	1	3%
bankmagi									5			5	5							5	5	5			5.0	6	25%		5		5.0	1	33%							0	0%	1.1	7	22%
bedfsali																										0	0%					0	0%					3	3.0	1	20%	0.1	1	3%
coppquad																										0	0%					0	0%	3				3	3.0	2	40%	0.2	2	6%
eucaamyg									5		5		10	10	3	5	5								6.1	7	29%					0	0%							0	0%	1.3	7	22%
eucaobli			5															5	5				5		5.0	4	17%		5		5.0	1	33%							0	0%	0.8	5	16%
eucaovat				5												10									7.5	2	8%					0	0%							0	0%	0.5	2	6%
eucavimi	10		5	5			5	5	5		5	5	5				5	5	5				5		5.4	13	54%					0	0%	10					10.0	1	20%	2.5	14	44%
exoccupr														10				3	5	15		5			7.6	5	21%			10	10.0	1	33%		3	3	5	25	9.0	4	80%	2.6	10	31%
leptscop					5		5			5										5	10			5	5.8	6	25%		5		5.0	1	33%							0	0%	1.3	7	22%
melasqua		5	30		15		20		10			5	10	5	20	15				5	10	5		80	16.8	14	58%	80	5		42.5	2	67%				10		10.0	1	20%	10.3	17	53%
ozothamn														5											5.0	1	4%					0	0%							0	0%	0.2	1	3%
zierarbo																										0	0%					0	0%	3					3.0	1	20%	0.1	1	3%
Understorey																										0	0%					0	0%							0	0%	0.0	0	0%
blecwata																										0	0%	5	5		5.0	2	67%							0	0%	0.3	2	6%
diantasm						5								5	10				5						6.3	4	17%		5		5.0	1	33%			3	5		4.0	2	40%	1.2	7	22%
gleidica																										0	0%	20	15		17.5	2	67%							0	0%	1.1	2	6%
goodovat																										0	0%					0	0%					5	5.0	1	20%	0.2	1	3%
gymnspha																										0	0%	5	10		7.5	2	67%							0	0%	0.5	2	6%
juncussp					5			5																	5.0	2	8%					0	0%					5	5.0	1	20%	0.5	3	9%
lepidosp					5																				5.0	1	4%					0	0%	10					10.0	1	20%	0.5	2	6%
leptscop											5		10			15	5								8.8	4	17%		5	5	5.0	2	67%	40					40.0	1	20%	2.7	7	22%
lomalong		5	5			5	5			5		5	5	5	5	5	5	3	5		5				4.9	14	58%		5	25	15.0	2	67%							0	0%	3.1	16	50%
melasqua											5														5.0	1	4%					0	0%							0	0%	0.2	1	3%
oxylelli																5								5	5.0	2	8%					0	0%							0	0%	0.3	2	6%
poaspp																							5		5.0	1	4%		10		10.0	1	33%							0	0%	0.5	2	6%
pteresca		95	95	45	70	95	90	35	90	90	90	70	90	90	85	95	90	95	40	100	80	100	80	60	81.3	23	96%	5	50	10	21.7	3	100%	25	30	90	75	20	48.0	5	100%	68.0	31	97%
restiona																										0	0%	5			5.0	1	33%							0	0%	0.2	1	3%
senecios														5											5.0	1	4%					0	0%	5					5.0	1	20%	0.3	2	6%

Appendix 4: Example of *P. quadragintus* Habitat Assessment

A. *E. viminalis* tree survey

1. DBH: tree diameter at breast height (130 cm from ground)

2. Tree height

3. Distance to nearest canopy: distance to the nearest white gum canopy
   1 = Overlap, 2 = <5m, 3 = 5-10m, 4 = 10-15m, 5 = >15m

4. Crown condition: 3 parameters are used for the crown condition assessment. Scored 1-5

   1) canopy size & shape: 1 = contracted, 3 = moderate, 5 = large, vigorous

   2) dead branches: 1 = dead main branches (large and small), 2 = dead main branches (some large and or small), 3 = dead small branches, 4 = dead terminal shoots, 5 = nil

   3) crown transparency: 1 = 0-5 %, 2 = 5-25 %, 3 = 25-50 %, 4 = 50-75 %, 5 = >75 %

   - Scoring details for each parameters and photos are in the Crown Condition Assessment Index

   - It is important to be able to clearly see the crown, because canopies can be uneven, with some areas exhibiting different characteristics. This problem needs to be minimised by first observing the tree from various positions and then using this knowledge when assessing the canopy from the clearest position (Horton *et al.*, 2010).

5. Slope: the slope level where the surveyed trees grow
   1 = flat (< 1°), 2 = gentle slope (1-15°), 3 = moderate slope (15-45°), 4 = steep slope (> 45°)

B. *P. quadragintus* Habitat survey

6. Canopy cover: estimation from the ground
7. Presence of potential nesting site (log, stump, and dead tree with hollows etc.)
8. *E. viminalis* recruitment (number of seedlings and juveniles)
9. Dead and live large non-*E. viminalis* trees (DBH)

A. *E. viminalis* tree survey

Date: ____________ Site name: ______________________________ Patch no.: __________

Surveyor(s): ______________________________ Grid reference ______________________________

No.	DBH (cm)	Height (m)	Distance to nearest canopy*	Structure & Crown condition**			Slope ***	Notes
				Size & shape	Dead branches	Crown transparency		

* Distance to nearest *E .viminalis* canopy: 1 = Overlap, 2 = <5m, 3 = 5-10m, 4 = 10-15m, 5 = >15m

**Crown condition (see crown condition assessment index)

Size & shape: 1 = contracted, 3 = moderate, 5 = large, vigorous

Dead branches: 1 = dead main branches (large and small), 2 = dead main branches (some large and or small), 3 = dead small branches, 4 = dead terminal shoots, 5 = nil

Crown transparency: 1 = 0-5 %, 2 = 5-25 %, 3 = 25-50 %, 4 = 50-75 %, 5 = >75 %

***Slope: 1 = flat (< 1°), 2 = gentle slope (1-15°), 3 = moderate slope (15-45°), 4 = steep slope (> 45°)

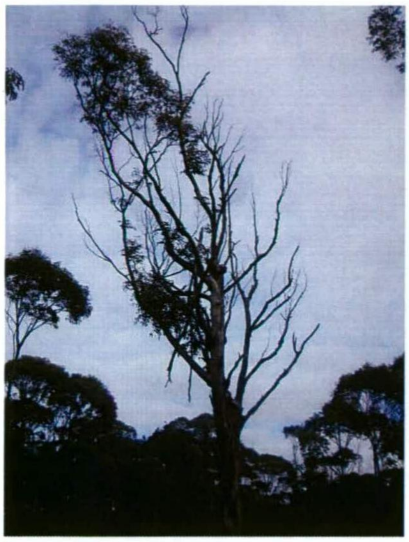
B. *P. quadragintus* habitat survey

Canopy cover	*E. viminalis* ( ), *E amygdalina* ( ), *E. obliqua* ( ) *E. puchella* ( ), *E. globules* ( ), *E. ovata* ( ) *E. tenuiramis* ( ), Other species					
Presence of potential nesting site	E.g. log, stamp, and dead tree etc.					
E. viminalis recruitment (number of seedlings and juveniles*)	Seedlings:			Juveniles:		
Dead and live large non-*E. viminalis* trees (DBH)	Tree species	DBH	Dead/Live	Tree species	DBH	Dead/Live

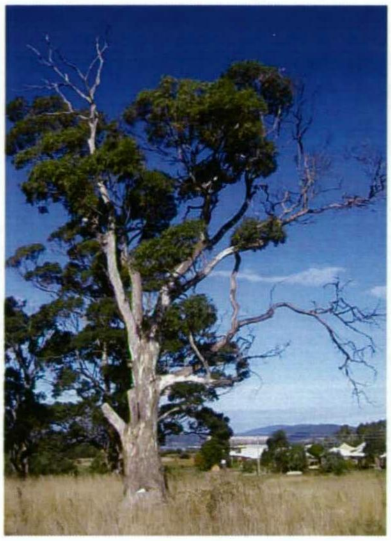
E. viminalis Crown Condition Assessment Index

(modified version of Stone *et al.*, 2003, photos taken by C. Iijima)

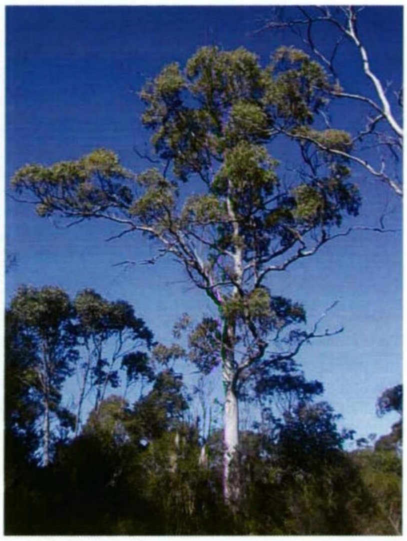
1. Overall canopy size and shape



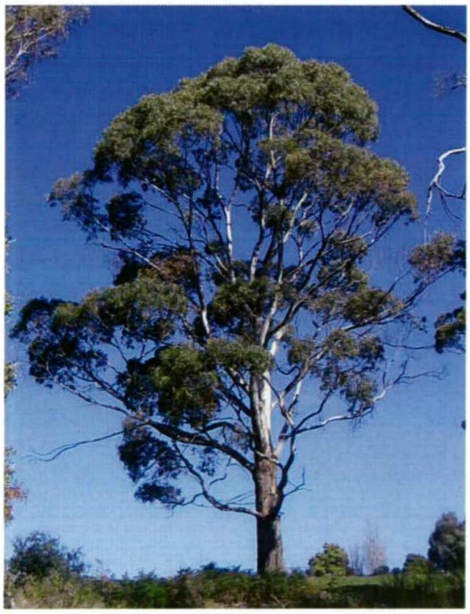
Score 1: Contracted
Canopy contracted, unbalanced or cylindrical in shape, foliage on only minor branches or stem arising from epicormic growth



Score 2: Intermediate
The condition appeared between score 1 and 3.



Score 3: Moderate
Moderate-size canopy, often co-dominant, non-uniform in shape. Few major branches present.



Score 4: Moderate Intermediate
The condition appeared between score 3 and 5.

Score 5: Large, vigorous
Large, well balanced canopy, shaped by several large branches containing a healthy 'hierarchy' of smaller branches

2. Dead branches

Score 1: Dead main branches
Large and small branches dead over most of the crown which is obviously dying

Score 2: Dead main branches
Some large and/or small branches dead over part of the crown with the obvious impression of serious branch death

Score 3: Dead small branches
Some small branches are dead but not over the entire crown. These are easily observed but do not give the impression of seriously affecting the crown

Score 4: Dead terminal shoots
On close inspection some dead terminal branches are evident but not over all the crown

Score 5: No visible dead branches or branchlets/shoots in the crown

3. Crown transparency

Score 1: cover < 5%

Score2: cover 5-25%

Score 3: cover 25-50%

Score 4: cover 50-75%

Score 5: cover >75%

Appendix 5: Mean DBH and height for *E. viminalis* at all quadrats in the Coffee Creek and Township sites

Sites followed by the same letter are not different at $P<0.05$ by Tukey-Kramer HSD test

DBH

Quadrat no.	n		Mean DBH (cm)	SE
C15	7	A	83.1	12.48
C5	7	A	81.0	12.48
C10	9	A	79.6	11.01
C2	10	A	73.8	10.45
T15	11	A	72.4	9.96
C4	9	A	71.5	11.01
C1	8	A	68.7	11.68
T12	7	A	68.3	12.48
C8	10	A	66.3	10.45
C14	8	A	65.5	11.68
C16	11	A	64.8	9.96
C3	8	A	60.2	11.68
C21	14	A	57.9	8.83
T6	5	A	56.4	14.77
T2	5	A	55.7	14.77
T9	7	A	53.9	12.48
T13	7	A	52.2	12.48
T11	9	A	51.0	11.01
C18	4	A	50.8	16.52
T5	6	A	50.5	13.49
C19	11	A	47.6	9.96
T4	11	A	47.2	9.96
C12	7	A	45.9	12.48
C6	10	A	45.1	10.45
T10	9	A	44.8	11.01
T3	7	A	42.8	12.48
T14	19	A	41.3	7.58
T1	6	A	40.5	13.49
C9	8	A	39.7	11.68
T8	13	A	38.9	9.16
C7	9	A	38.0	11.01
C11	8	A	37.3	11.68
C20	9	A	35.9	11.01
C13	9	A	33.7	11.01
T7	6	A	32.3	13.49
C17	10	A	28.7	10.45

Height

Quadrat no.	n		Mean height (m)	SE
T12	7	AB	24.0	1.90
T15	11	A	23.9	1.52
T4	11	AB	23.1	1.52
C6	10	ABC	22.8	1.59
C14	8	ABCD	21.9	1.78
C11	8	ABCD	21.3	1.78
C19	11	ABCD	21.0	1.52
T1	6	ABCDE	20.8	2.05
C10	9	ABCDE	20.8	1.68
C9	8	ABCDE	20.8	1.78
T2	5	ABCDE	20.6	2.25
C5	7	ABCDE	20.4	1.90
C3	8	ABCDE	20.1	1.78
T3	7	ABCDE	20.0	1.90
C1	8	ABCDE	19.8	1.78
C16	11	ABCDE	19.7	1.52
C18	4	ABCDE	19.3	2.51
C4	9	ABCDE	18.9	1.68
C21	14	ABCDE	18.9	1.34
C15	7	ABCDE	18.6	1.90
C2	10	ABCDE	18.5	1.59
C8	10	ABCDE	18.5	1.59
T13	7	ABCDE	18.4	1.90
T8	13	ABCDE	17.8	1.39
T6	5	ABCDE	17.8	2.25
C12	7	ABCDE	17.3	1.90
C13	9	ABCDE	17.2	1.68
C17	10	ABCDE	17.2	1.59
T7	6	ABCDE	16.5	2.05
C20	9	ABCDE	15.4	1.68
T11	9	BCDE	14.9	1.68
T14	19	DE	14.8	1.15
T5	6	BCDE	14.8	2.05
C7	9	CDE	14.0	1.68
T10	9	DE	13.2	1.68
T9	7	E	11.1	1.90

Appendix 6: Variables which indicate fire and no fire groups and sand and dolerite groups

Fire and no fire groups

Variable	Maxgrp	Value (IV)	Mean	S.Dev	p *
AcacdeaM	0	29.5	15	5.8	0.044
AcacmelM	0	60.8	40.2	6.86	0.01
LeptscoM	0	23.8	11.7	5.37	0.056
DiantasU	0	44.1	20.5	6.95	0.013
PterescU	0	70.7	45	6.26	0.002
Leaf	0	55.4	51.8	2.18	0.023
AcacvarM	1	48	24.8	6.84	0.017
BersspiM	1	52	26.4	6.92	0.007
PoasppU	1	56	27.7	7.13	0.006
Vegetati	1	65.8	37.6	7.13	0.004
Rock	1	54.1	30.6	6.97	0.014

Plant species and type of ground cover annotated at $P < 0.05$ are deemed to be indicative of past fire evidence. 0 = no evidence of fire; 1 = evidence of fire

Sand and dolerite groups

Variable	Maxgrp	Value (IV)	Mean	S.Dev	p *
EucagloO	0	40	14.9	4.25	0.002
EucapluO	0	46.7	16.6	5.93	0.003
AcacvarM	0	80	24.1	6.11	0.001
BersspiM	0	86.7	25.6	6.2	0.001
CoppquaM	0	46.7	16.4	5.61	0.001
AstrhumU	0	26.7	11.5	4.79	0.027
LepidosU	0	33.3	13.7	5.26	0.008
PoasppU	0	93.3	27.1	6.16	0.001
ThemtriU	0	46.7	16.4	5.79	0.001
Vegetati	0	89.9	37.1	6.31	0.001
Rock	0	96.7	29.9	6.31	0.001
EucaamyO	1	47.6	21	5.94	0.002
EucavimO	1	61	52	2.27	0.001
AcacmelM	1	66	39.6	6.12	0.003
MelasquM	1	42.9	19.4	6.06	0.005
DiantasU	1	42.9	19.6	5.87	0.006
PterescU	1	93.6	44.6	5.48	0.001
Leaf	1	58.3	51.8	2.11	0.001

Plant species and type of ground cover annotated at $P < 0.05$ are deemed to be indicative of soil types. 0 = dolerite ; 1 = sand

* proportion of randomized trials with indicator value equal to or exceeding the observed indicator value.
p = (1 + number of runs >= observed)/(1 + number of randomized runs)
Maxgrp = Group identifier for group with maximum observed IV

Appendix 7: Leaf damage caused by insects

Scoring index of leaf area loss

Intact | 1 = < 1 % | 2 = 1-5 % | 3 = 5-10% | 4 = 10-20% | 5 = 20-50% | 6 = > 50%

Type of insect damages

Gall + chewing on edge | Erosion | Lerp + chewing on edge | Chewing in interior + on edge

Appendix 8: Leaf damage at each patch

Patch no.	n	Leaf area loss*		Gall	Erosion	Leaf mine	Lerps	Chewing on eade	Chewing in interior
		Mean	SE	%	%	%	%	%	%
1	74	3.18	0.22	14.86	54.05	0	0	81.08	21.62
2	95	1.94	0.19	10.53	40.00	0	0	60.00	5.26
3	83	2.19	0.20	12.05	40.96	0	0	66.27	6.02
4	29	2.86	0.35	17.24	24.14	0	0	86.21	3.45
5	137	1.28	0.16	1.46	42.34	0	0	37.96	6.57
6	121	2.17	0.17	9.09	49.59	0	0	67.77	15.70
7	100	2.54	0.19	5.00	44.00	0	0	72.00	13.00
8	115	2.47	0.17	7.83	22.61	1.74	0	76.52	8.70
9	94	3.74	0.19	15.96	60.64	0	0	97.87	13.83
10	77	2.39	0.21	14.29	87.01	0	0	79.22	7.79
11	43	2.81	0.28	39.53	6.98	0	0	86.05	11.63
12	98	3.47	0.19	4.08	52.04	0	0	88.78	18.37
13	65	3.35	0.23	23.08	50.77	0	0	89.23	9.23
14	94	3.15	0.19	13.83	59.57	0	0	80.85	8.51
15	53	3.58	0.26	20.75	47.17	1.89	0	86.79	5.66
16	88	3.24	0.20	2.27	46.59	2.27	0	88.64	6.82
17	63	2.87	0.23	12.70	30.16	0	0	84.13	17.46
18	62	3.26	0.24	19.35	45.16	0	0	85.48	17.74
19	56	2.86	0.25	14.29	39.29	0	0	80.36	5.36
20	67	3.24	0.23	5.97	38.81	0	0	85.07	2.99
21	100	2.84	0.19	11.00	34.00	1	0	71.00	9.00
22	83	2.00	0.20	15.66	26.51	0	0	66.27	3.61
23	74	3.18	0.22	18.92	25.68	0	0	90.54	4.05
24	38	2.58	0.30	10.53	34.21	0	0	78.95	13.16
25	58	4.12	0.24	17.24	51.72	0	0	89.66	6.90
26	51	2.90	0.26	9.80	45.10	0	0	84.31	7.84
27	31	3.23	0.33	3.23	80.65	0	0	77.42	12.90
28	101	2.91	0.19	7.92	52.48	0	0	82.18	6.93
29	91	3.09	0.20	2.20	57.14	0	0	89.01	6.59
30	69	2.70	0.22	7.25	60.87	0	0	82.61	7.25
31	23	2.17	0.39	26.09	34.78	0	0	65.22	17.39
32	71	2.76	0.22	5.63	54.93	0	0	90.14	8.45

*Leaf area loss score: 1 = < 1%, 2 = 1-5%; 3 = 5-10%; 4 = 10-20%; 5 = 20-50%; and 6 = > 50%
For the other type of damages (gall. erosion, leaf mine, lerps. chewing on edge and chewing in interior), percentage of the leaves with each damages were calculated at each patch.

Appendix 9: Patch attribute variables

Patch no	Bird detection rate (%)	Total number of detected birds	Patch group	Area size (ha)	Easting	Northing	Number of surveyed trees	Ev%	Ea%	Eob%	Eov%	Eg%	E.v. Age structure	Aspect	mean DBH	min DBH	max DBH	mean Height	min Height	maxHeight	mean SDC	min SDC	max SDC	mean Altitu	Leaf area loss
1	0.0	0	Coffee Creek	0.31	523788	5240080	6	95	5	0	0	0	un-even	SE	116.3	92.7	154.5	27.2	24.0	33.0	10.7	10	12	55.0	3.18
2	12.5	0	Coffee Creek	1.63	523841	5239803	39	80	10	10	0	0	un-even	SE	79.7	15.9	176.8	20.6	7.0	36.0	8.0	3	11	47.9	1.94
3	0.0	0	Coffee Creek	1.27	523885	5239681	16	85	5	5	5	0	un-even	SE	64.2	19.1	144.9	17.9	8.0	30.0	8.2	5	10	45.4	2.19
4	0.0	0	Coffee Creek	0.11	523811	5239634	15	70	0	0	5	0	un-even	E	52.3	20.5	149.7	16.7	11.0	21.0	11.4	9	13	57.3	2.86
5	0.0	0	Coffee Creek	0.45	523867	5239512	8	65	10	0	0	0	un-even	SW	91.8	19.6	168.5	91.8	19.6	168.5	7.0	3	9	41.1	1.28
6	0.0	0	Coffee Creek	0.97	523853	5239392	15	85	0	0	0	0	even	S	65.5	24.8	172.9	23.1	15.0	34.0	6.6	4	9	37.7	2.17
7	14.3	1	Coffee Creek	1.30	523949	5239450	28	15	20	0	0	0	un-even	SW	38.4	16.0	79.6	11.4	7.0	18.0	8.3	7	11	46.1	2.54
8	0.0	0	Coffee Creek	0.57	523811	5239518	13	60	0	0	0	0	un-even	SW	110.2	41.2	209.9	20.0	14.0	26.0	8.0	6	11	45.3	2.47
9	40.0	3	Coffee Creek	0.96	523869	5239225	17	30	30	0	0	0	un-even	S	24.9	15.4	58.4	12.4	8.0	16.0	7.3	5	9	39.0	3.74
10	11.1	2	Coffee Creek	2.43	523724	5238970	20	80	15	0	0	0	even	SW	62.0	19.0	161.5	20.2	10.0	34.0	8.5	5	10	29.9	2.39
11	0.0	0	Coffee Creek	0.73	523809	5238956	6	5	70	0	0	0	un-even	S	45.3	20.1	98.3	13.8	10.0	21.0	9.3	9	10	34.0	2.81
12	30.0	3	Coffee Creek	1.44	523688	5238795	17	80	5	5	0	0	un-even	S	78.7	38.7	153.8	19.8	14.0	31.0	8.9	5	11	35.2	3.47
13	8.3	6	Coffee Creek	2.83	523828	5238721	82	20	30	0	0	0	un-even	N	38.8	15.0	127.4	15.5	6.0	28.0	8.3	4	12	28.7	3.35
14	0.0	0	Coffee Creek	1.39	523806	5238536	35	55	5	15	0	0	un-even	S	50.4	15.2	124.5	17.4	8.0	31.0	8.6	3	12	29.0	3.15
15	0.0	0	Coffee Creek	0.40	523722	5238471	19	60	5	5	0	0	even	S	29.2	15.7	78.5	15.3	10.0	25.0	7.0	3	10	27.5	3.58
16	20.0	1	Coffee Creek	0.80	523649	5238361	21	45	35	0	0	0	even	S	86.6	22.7	233.7	21.1	10.0	27.0	8.5	6	12	23.3	3.24
17	0.0	0	Coffee Creek	0.99	523580	5238244	16	65	25	0	0	0	un-even	S	59.4	23.0	123.9	18.7	13.0	26.0	7.7	5	10	17.0	2.87
18	41.7	11	Coffee Creek	2.51	523384	5238216	30	35	0	25	0	0	un-even	S	57.9	15.5	165.0	19.7	11.0	38.0	8.6	3	12	9.4	3.26
19	0.0	0	Coffee Creek	1.05	523291	5238313	18	45	0	35	0	0	un-even	SW	85.3	33.9	197.5	23.6	15.0	34.0	7.9	4	11	13.3	2.86
20	16.7	2	Coffee Creek	0.73	523534	5238164	12	45	5	40	0	0	even	SW	32.5	16.5	77.0	17.0	13.0	21.0	7.2	6	8	13.3	3.24
21	0.0	0	Coffee Creek	1.89	523527	5238014	63	15	15	5	0	0	un-even	N	35.1	15.7	73.1	15.8	9.0	24.0	8.5	5	11	15.0	2.84
22	0.0	0	Coffee Creek	1.25	523427	5238064	21	80	0	0	5	0	even	SE	61.9	26.5	128.3	24.2	18.0	29.0	8.7	3	12	17.8	2.00
23	25.0	2	Coffee Creek	2.95	523320	5237958	24	40	5	40	0	0	un-even	W	68.2	18.5	207.0	20.4	10.0	29.0	8.7	7	11	7.9	3.18
24	0.0	0	Coffee Creek	0.08	523940	5239898	9	90	5	5	0	0	even	SW	43.6	30.3	86.7	18.3	16.0	22.0	10.6	8	12	67.4	2.58
25	0.0	0	Mid-eastern	0.62	524511	5239127	79	65	15	0	20	0	un-even	S	30.7	15.2	78.8	14.5	7.0	27.0	8.8	4	12	57.0	4.12
26	16.7	1	Mid-eastern	1.68	524439	5239040	38	35	30	35	5	0	un-even	S	32.9	15.0	81.0	14.5	8.0	21.0	8.6	4	11	44.0	2.90
27	0.0	0	Mid-eastern	1.99	524898	5238705	68	10	15	0	0	0	even	NW	23.5	15.0	60.5	12.5	7.0	19.0	7.0	4	10	98.7	3.23
28	0.0	0	Channel Highway	1.30	523237	5238957	43	60	0	30	0	0	un-even	SE	72.8	26.3	170.0	22.0	8.0	30.0	9.1	6	12	43.1	2.91
29	50.0	3	Channel Highway	1.37	522866	5239172	35	45	10	15	0	0	even	E	77.6	20.0	197.4	21.7	12.0	31.0	9.1	6	12	87.2	3.09
30	0.0	0	Channel Highway	1.00	522833	5239042	18	10	40	30	0	0	un-even	E	39.1	18.8	93.3	19.4	15.0	28.0	8.2	5	12	79.9	2.70
31	100.0	6	Channel Highway	1.79	522819	5238898	36	40	0	40	0	0	un-even	E	62.9	27.6	124.7	20.4	12.0	27.0	9.2	6	12	55.8	2.17
32	0.0	0	Channel Highway	1.04	522655	5239026	17	45	0	45	0	5	even	E	53.7	32.4	111.5	22.4	19.0	29.0	9.6	6	12	69.5	2.76

Appendix 10: Building and road development in Howden 1990 to 2005 (from street atlas)

Section	1990				1998				2005			
	Building		Road		Building		Road		Building		Road	
	Total no.	Frequency	Total no.	Frequency	Total no.	Frequency	Total no.	Frequency	Total no.	Frequency	Total no.	Frequency
East	995	11	83	10	1215	12	89	11	1346	12	104	11
North	299	13	40	13	506	14	51	14	584	15	58	14
South	93	8	15	9	127	12	23	11	159	14	22	11
West	33	8	10	7	34	8	12	7	31	8	10	7
Total	1420	40	148	39	1882	46	175	43	2120	49	194	43